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THE BBN 940 LISP SYSTEM

Daniel G. Bobrow
D. Lucille Darley
L. Peter Deutsch
Daniel L. Murphy
Warren Teitelman

Bolt Beranek and Newman Inc
50 Moulton Street
Cambridge, Massachusetts 02138

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ABSTRACT

This report describes the LISP system implemented at BBN on the
SDS 94Ø Computer. This LISP is an upward compatible extension of
LISP 1.5 for the IBM 7090, with a number of new features which
make it work well as an on-line language. These new features
include tracing, and conditional breakpoints in functions for
debugging and a sophisticated LISP oriented editor. The BBN 94Ø
LISP SYSTEM has a large memory store (approximately 50,000 free
words) utilizing special paging techniques for a drum to provide
reasonable computation times. The system includes both an
interpreter, a fully compatible compiler, and an assembly language
facility for inserting machine code subroutines.

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SECTION I

INTRODUCTION

LISP is a highly sophisticated list-processing language which is being used extensively in artificial intelligence research. This document describes the BBN 940 LISP system, which has a number of unique features which make it a very good on-line interactive system with a large drum memory. Ideally, a LISP system would have a very fast, random-access memory. However, magnetic core memory (the only large scale random-access memory available) is very expensive relative to serial memory devices such as magnetic drums or discs. Since average access time to a word on a drum or disc is many times slower than access to a word in a core memory, using a drum as a simple extension of core memory would reduce considerably the operating speed of such a system. We have developed special paging techniques which allow utilization of a drum for storage with a much smaller penalty in speed. These techniques are described in detail in Bobrow and Murphy's "Structure of LISP Using Two-Level Storage," (Comm. ACM, March 1967).

Although we have tried to be as clear and complete as possible, this document is not designed to be an introduction to LISP. Therefore, some parts may be clear only to people who have had some experience with other LISP systems. A good introduction to LISP is Clark Weisman, "LISP 1.5 Primer" (Dickenson Press 1967). Although not completely accurate with respect to the BBN 940 LISP system, the differences are small enough to be mastered by use of this manual and on-line interaction. Other important references, published by the MIT Press, are John McCarthy, LISP 1.5 Programmer's Manual and Berkeley and Bobrow (editors), The Programming Language LISP, Its Operation and Applications.

SECTION II

USING THE LISP SUBSYSTEM ON THE 940

In order to use LISP, you must have in your files a <u>sysout</u> file
of the basic system. This basic LISP system file, usually called
LISP, contains a binary image of LISP after it has been initial-
ized and loaded with the library. You do not need a copy of the
library if you have this file.

Call LISP by typing <u>LIS</u>; the system will respond P; then type .;
when LISP finally responds READY, and types ←, you are talking to
the LISP supervisor, usually called <u>evalquote</u>. Then type the
following:

    SYSIN (LISP)

After typing the above, the system will find and load the basic
system binary file of this name from tape. When it has read it
in successfully, it will respond with a T, and the LISP super-
visor will again type ←, indicating that it is listening to you
again.

When typing in to <u>evalquote</u>, typing a control-Q will clear the
input <u>line</u> buffer erasing the entire line up to the last carriage
return. Typing control-A erases the last character typed in,
echoing a ↑ and the erased character; it will not go beyond the
last carriage return. Pressing the RUBOUT button while in the
middle of a typein to the LISP executive, <u>evalquote</u>, will clear
the entire <u>read</u> buffer of everything back to the last ←, and
LISP will again type ←.

The LISP read program counts parentheses, and echoes a carriage return when all left and right parentheses balance. Left and right brackets, "[" and "]", are super-parentheses. A right bracket will close all open left parentheses up to the last open left bracket; if there is no open left bracket, it will close the entire expression. For example:

PRINT ((THIS IS A LISP SYSTEM FROM BBN (FOR THE 940]

will print the expression shown with enough right parentheses to close all lists; that is, the "]" is equivalent, in this case, to three right parentheses. Unpaired right parentheses are read as NIL.

To exit from LISP, type:

LOGOUT ()

One can then execute any system commands, except those which start another subsystem, and continue LISP using the system CONTINUE command. This will revive the LISP system exactly as you left it, except that all open files will be closed, and you will be typing to evalquote, whether or not you executed the logout at the top level.

SECTION III

DATA TYPES AND THE ORGANIZATION OF VIRTUAL MEMORY

LISP operates in a 21-bit address space, though only that portion
currently in use actually exists on the drum. A portion of the
address space above that actually allocated for structures is
used for representation of small integers, as described below.
All data storage is contained within this virtual memory,
including literal atoms, list structure, arrays and compiled code,
large integers, floating point numbers, and pushdown list storage.
This virtual memory is divided into pages of 256 words. References
to the virtual storage are made via an in-core map which supplies
the address of the required page if it is in core, or traps to a
supervisory routine if the page is not in core. This drum super-
visory routine selects an in-core page, writes it back on the
drum if it has been changed, and reads the required page from the
drum. Closed subroutine references to an in-core word through
the map take approximately 40 microseconds. A reference to a
word not in core, which must be obtained from the drum, takes up
to 33 milliseconds, the drum maximum access time. It takes twice
as long if a page must be written out on the drum before the
referenced page can be read in.

Type Determination of Pointers

The virtual memory is divided into a number of areas as shown in
Fig. 1. As can be seen from this map of storage, simple arith-
metic on the address of a pointer will determine its type. We
chose to allocate storage rather than provide in-core descrip-
tors of storage areas, because they would take up valuable in-core
space.
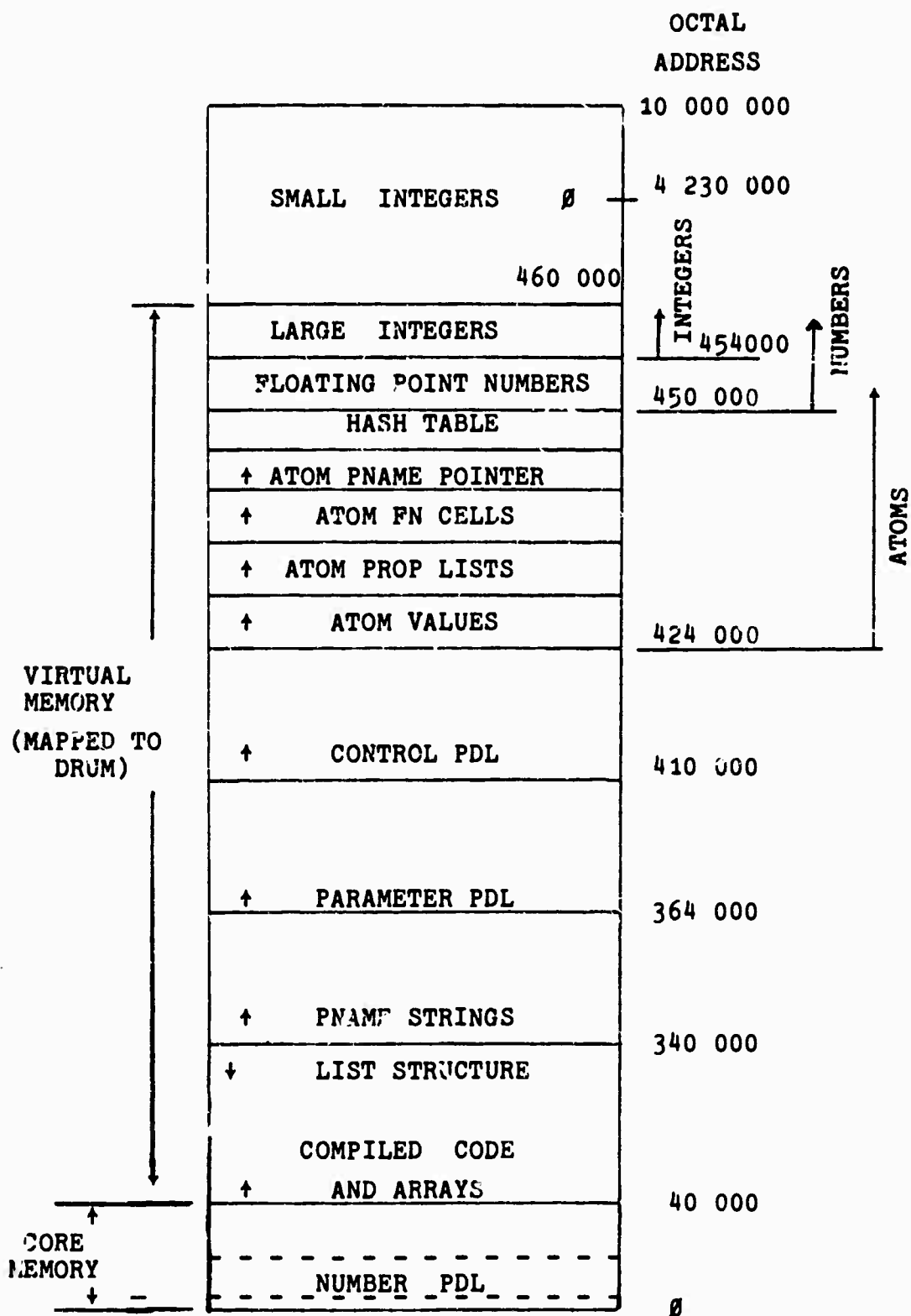
FIG. 1 MEMORY ALLOCATION IN LISP

Literal Atoms

A literal atom is constructed from any string of characters not
interpretable as an integer or a floating point number. When a
string of characters representing a literal atom is read in, a
search is made to determine if an atom with the same print-name
has been seen before. If so, a pointer to that atom is used for
the current atom. If not, a new atom is created. Thus, as in all
LISP systems, a literal atom has a unique representation.

Four cells (940 words) are associated with each literal atom.
These cells contain pointers to the print-name of the atom, the
function which it identifies, its top level or global value, and
its property list. Since pointers to atoms occur in only one
part of the address space, one can tell from a pointer (address)
whether or not it is pointing to a literal atom.

Instead of having the four cells associated with each atom on the
same page, each is put in a separate space in a position compu-
table from the pointer to the atom.

Separating value cells and function cells, for example, is useful
because most users will not use the same name for a global
variable as they will for a function. Therefore, if the four
cells were brought in whenever any one was asked for, it is
likely that the other three cells would never be referenced. Yet,
they use up room in core which could be used for other storage.
Similarly, the print-name pointers associated with atoms are
needed during input and output, but rarely during a computation.
Therefore, during computation these cells are never in core.

Car of a literal atom usually contains the top level binding of
the atom. If the atom has not yet been bound, the value cell

contains the special atom NOBIND. cdr of the atom is a pointer
to the atom property list, initially NIL. The PNAME cell contains
a pointer to a packed character table which contains the print-
name of the atom. The function cell contains NIL until a function
by that name is defined. One implication not immediately obvious
is that car[NIL] = NIL, and cdr[NIL] = NIL. These latter two
values are a significant convenience in programming.

Numerical Atoms

Integers

In LISP, most numerical atoms (numbers) do not have a unique re-
presentation; that is, a number of different pointers may reference
numbers with the same value. This implies that for comparison of
numbers, or for arithmetic operations, the values of the numbers
must be obtained. The values of floating point numbers and large
integers are stored in a "full word" space. Pointers to these
values are used in list structure.

However, we utilize the fact that not all addresses in the virtual
address space of the drum can legitimately appear as pointers in
list structure. These "illegal" pointers are therefore used in
the context of list structure to represent "small" integers
directly, offset by a constant.

The input format for an integer is any string of digits, option-
ally preceded by a "+" or "-". Integers must have magnitude less
than 2^{23}. "Small" integers are those of magnitude below approxi-
mately 2^{18} (an assembly parameter). A string of digits followed
by a "Q" will be interpreted as an octal number.

Floating Point Numbers

Floating point numbers and operations are available in BBN LISP.
They are stored in two contiguous 24 bit words in standard 940
format, in full word space. When creating an atom with read,
ratom or pack, LISP will recognize as a floating point number a
string of digits containing a decimal point. The letter "E"
(exponent of 10; i.e. yyExx=yy * 10^{xx}) will also serve to desig-
nate a floating point number if preceded and followed by one or
more digits. The following are legal floating point input strings.

    5.   5.0   5E0   5E-3   5.2E+6   .3

The floating point/string conversion, and the floating point
arithmetic are performed by the POP's and BRS's available in the
940 system. Additional information concerning conversion and
precision is available from the system documentation of these
routines.

The atom printing routine (used by prin1, prin2, prin3, unpack)
will call the system conversion routine when it encounters a
floating point datum. The output format is controlled by the
function fltfmt[n] described later.

Arrays

Arrays in BBN LISP have the following format.
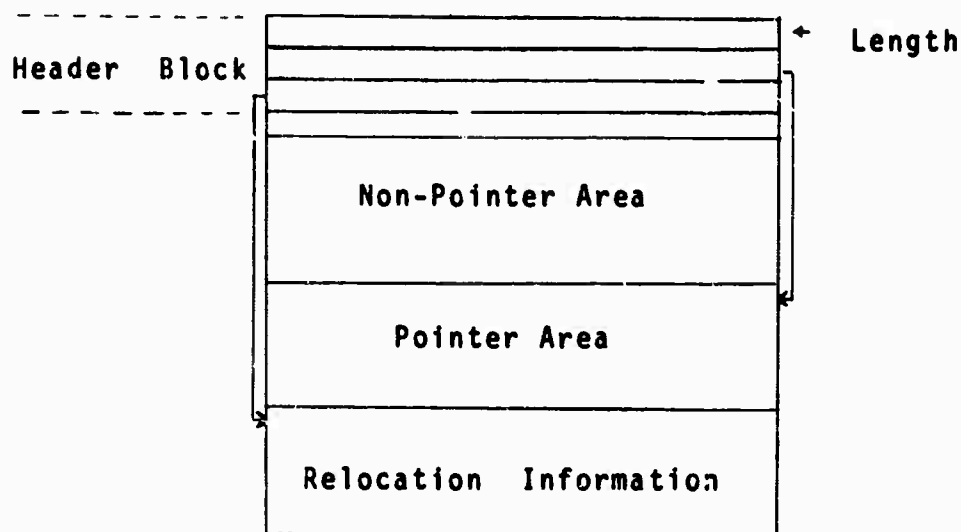
Typical Array

The HEADER BLOCK is four cells long and contains:

Cell: ∅   Length of entire array.

            1   Relative address of first word of protected pointers.

            2   Relative address of first word of relocation information.

            3   ∅ if an integer or symbolic array.
                 1 if a floating point array.
                 Used as temporary storage in compliled code.

An array may contain both pointer and non-pointer data, separated as shown. Pointer data is assumed to be one of the standard LISP types, and the pointer data cells in all arrays are used as base cells for tracing during garbage collection. The non-pointer data, beginning in the fifth cell of the array, is of unrestricted type, and will not be used as trace pointers during garbage collection.

Relocation information contains the relative addresses of cells in the array which are to be relocated when the array is used as a compiled function, and is placed in core memory.

Examples:

1. Compiled code.
   a. Machine instructions and unboxed numeric literals are in the non-pointer area.
   b. Other literals and variable name pointers are in the pointer area.
   c. Relocation information area addresses all machine instructions whose address is within the same program, e.g., BRANCH instructions.

2. Array of lists.
   All data would be in the pointer area; the other areas would be of length $\emptyset$.

3. Array of unboxed numbers.
   All data would be in the non-pointer area; tne other areas would be of length $\emptyset$.

List Structure

List Structure is created in list space as shown in the memory
map. Lists can contain pointers to all data types. As can be
seen from the map, list space and array space grow toward each
other. The total space available is an assembly parameter.
Currently the space available is 96K ($K=1024$) SDS 940 24 bit
words, which if used all for list storage would provide 48K words
of free storage.

SECTION IV

FUNCTION TYPES

There are basically eight function types in the BBN LISP System.
These eight types are characterized by three dichotomies. A
function may independently have:

1. its arguments evaluated or unevaluated,
2. a fixed number of arguments or an indefinite number of
    arguments.
3. be defined by a LISP expression, or by machine code
    (which may be permanent system code, or compiled
    machine code).

Expressions used to define functions must start with either
LAMBDA, or NLAMBDA; indicating that the arguments of this func-
tion are to be evaluated, or not evaluated, respectively.
Following the LAMBDA or NLAMBDA may be any atom (except NIL) or
a list of atoms (possibly empty). If there is a list of atoms,
each atom in the list is the name of an argument for the function
defined by the expression. Arguments for the function will be
evaluated or unevaluated, as dictated by LAMBDA or NLAMBDA, and
ired with these argument names. If an atom follows the LAMBDA
or NLAMBDA, this function has an indefinite number of arguments.
If it is an NLAMBDA expression, then the atom is paired to the
list of arguments (unevaluated) of the function; that is, to <u>cdr</u>
of the form in which this function name was <u>car</u>.

If a LAMBDA is f `lowed by an atom, each of its arguments, n, will
be evaluated in .rn and placed on the parameter push down list.
The atom following the LAMBDA is bound to the number of arguments
which have been evaluated. A built-in function arg[m] returns

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the value of the mth argument of this function from the push
down list. For m>n or m≤o, it is undefined.

Functions defined by expressions can be compiled by the LISP com-
piler, as described in the section on the compiler and lap. They
may also be written directly in machine code and the LAP assembly
language if the lap conventions are followed to allow linkage to
LISP functions. Functions created both by the ccmpiler and lap
are referred to as compiled functions. Built-in system coded
functions are called subroutines. To determine the type of any
function fn, you can use the function fntyp[fn]. The value of
fntyp is one of the following 12 types:

EXPR	CEXPR	SUBR
EXPR*	CEXPR*	SUBR*
FEXPR	CFEXPR	FSUBR
FEXPR*	CFEXPR*	FSUBR*

The types in the first column are all defined by expressions.
The * suffix indicates an indefinite number of arguments (i.e. an
atom following the LAMBDA or NLAMBDA). Functions of types in the
first two rows evaluate their arguments. The types in the second
column are compiled versions of the types in the first column, as
indicated by the prefix C. In the third column are the parallel
types for built-in subroutines. The prefix F again indicates no
evaluation of arguments. Thus, for example, a CFEXPR* is a
compiled form of an NLAMBDA expression with an atom following
the NLAMBDA.

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A standard feature of the BBN LISP system is that no error
occurs if a function is called with too many or too few arguments.
If a function is called with too many arguments, the extra argu-
ments are evaluated but ignored. If a function is called with
too few arguments, the unsupplied ones will be delivered as NIL.
This applies to both built-in and defined functions.

There is a function progn of an arbitrary number of arguments
which evaluates the arguments in order and returns the value of
the last (i.e., it resembles and is an extension of prog2).

The conditional expression has been generalized so that instead
of doublets it accepts n+1-tuplets which will be interpreted in
the following manner:

```
(COND
    (P1 E11 E12 E13)
    (P2 E21 E22)
    (P3)
    (P4 E41))
```

will be taken as equivalent to (in LISP 1.5):

```
(COND
    (P1 (PROGN E11 E12 E13''
    (P2 (PROGN E21 E22))
    (P3 P3)
    (P4 E41)
    (T NIL))
```

This is not exactly true, but only because P3 is not evaluated
a second time, if the value is needed in the third item in the

second conditional expression. Thus, a list in a cond with only
a predicate and no following expressions causes the value of the
predicate itself to be returned. Note also that NIL is returned
if all the predicates have value NIL. No error is invoked.

LAMBDA and NLAMBDA expressions also have implicit progn's; thus
for example

        *
        (LAMBDA (V1 V2) (F1 V1) (F2 V2) NIL)

is interpreted as

        (LAMBDA (V1 V2) (PROGN (F1 V1) (F2 V2) NIL))

The value of the last expression following LAMBDA (or NLAMBDA)
is returned as the value of the expression. In this example,
the function would always return NIL.

SECTION V

PRIMITIVE FUNCTIONS AND PREDICATES

Primitive Functions

car[x]

car gives the first element of a
list x, or the left element of a
dotted pair x. Nominally unde-
fined for literal atoms, it
usually gives the top level
binding (value) of a literal
atom x. For the usually undefined
case of a number, its value is
the number itself.

cdr[x]

cdr gives the tail of a list (all
but the first element). This is
also the right member of a dotted
pair. If x is a literal atom,
cdr[x] gives the property list
of x. Property lists are usually
NIL unless modified by the user.
If x is a number, cdr returns NIL.

caar[x] = car[car[x]]

cadr[x] = car[cdr[x]]

cddddr[x] =
    [cdr[cdr[cdr[cdr[x]]]]

All 30 combinations of nested
cars and cdrs up to 4 deep are
included in the system. Levels 1,
2 and 3 are subroutines; 4 is
compiled. All are compiled open
by the compiler.

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cons[x;y]   cons constructs a dotted pair of
                                   x and y. If y is a list, x be-
                                   comes the first element of that
                                   list. To minimize drum accesses
                                   the following algorithm is used
                                   for finding a page on which to
                                   put the constructed LISP word.

cons[x;y] is placed
    1) on the page with y if y is a list and there is room;
        otherwise
    2) on the page with x if x is a list and there is room;
        otherwise
    3) on the same page as the last cons if there is room;
        otherwise
    4) on a page in core if one is available with a specified
        minimum of storage; otherwise
    5) on any page with a specified minimum of storage.
        The specified minimum is presently 20 LISP words in
        both cases.

The user may effect the operation of cons with the following
function:

conspage[x]   causes the page on which x re-
                                   sides to be used for alternative
                                   3 above instead of the result of
                                   the previous cons. If x is an
                                   atom, alternative 4 or 5 will
                                   be taken.

conscount[]   Returns the number of conses
                               since LISP started up.

rplacd[x;y]   This very dangerous SUBR places
                               in the decrement of the cell
                               pointed to by x̲ the pointer y̲.
                               Thus it changes the internal list
                               structure physically, as opposed
                               to cons̲ which creates a new list
                               element. This is the only way
                               to get a circular list inside cf
                               LISP; that is by placing a
                               pointer to the beginning of a
                               list in a spot at the end of the
                               list. Using this function care-
                               lessly is one of the few ways to
                               really clobber the system. The
                               value of rplacd is x̲.

rplaca[x;y]   This SUBR is simi . to rplacd,
                               but it replaces the address
                               pointer of x̲ with y̲. The same
                               caveats which applied to using
                               rplacd apply to rplaca. The
                               value of rplaca is x̲. Rplaca
                               and rplacd of NIL are illegal.

quote[x]   This is a function that prevents
                               its argument from being evaluated.
                               Its value is x̲ itself.

cond[x]

The argument for cond is a list.
Each element of the list is it-
self a list containing n $\geq$ 1
items: the first is an expres.ion
whose value may be false or true
(that is NIL, or anything which
is not NIL); the rest may be any
expressions. This i the condi-
tional expression in the LISP
system. The meaning of it is:
if the first element of the first
list is true (not NIL), then the
following expressions are evalu-
ated. The value of the condi-
tional is the value of the last
expression in this sublist. If
there is only one element in the
n-tuplet, then the value of the
conditional is the value of this
element if it is not NIL.

This value of a conditional agrees
with that of LISP 1.5 for pairs
of items, but allows additional
flexibility. If the first ele-
ment of the first list is false
(=NIL), then the second sublist
is considered, etc. Thus, the
arguments are searched until a
first element of a list is found
which is not NIL. If none are
found, the value of the conditional
expression is NIL.

selectq[x;y_1;y_2;...;y_n;z]   This very useful function is used
to select a sequence of instruc-
tions based on the value of its
first argument $\underline{x}$. Each of the
$\underline{y}_i$ is a list of the form

$$(\underline{s}_i \ \underline{e}_{1i} \ \underline{e}_{2i} \cdots \underline{e}_{ki})$$

where $\underline{s}_i$ is the selection key.

If $\underline{s}_i$ is an atom the value of $\underline{x}$
is tested to see if it is $\underline{eq}$ to
$\underline{s}_i$ (not evaluated). If so, the

expressions $\underline{e}_{1i},...\underline{e}_{ki}$ are eval-

uated in sequence, and the value
of the selectq is the value of
the last expression evaluated,
i.e. $\underline{e}_{ki}$.

If $\underline{s}_i$ is a list, and if any ele-
ment of $\underline{s}_i$ is $\underline{eq}$ to the value of
$\underline{x}$, then $\underline{e}_{1i}$ to $\underline{e}_{ki}$ are evaluated
in turn as above.

If $\underline{y}_i$ is not selected in one of
the two ways described then
$\underline{y}_{i+1}$ is tested, etc. until all
the $\underline{y}$'s have been tested. If
none is selected, the value of
the $\underline{selectq}$ is the value of $\underline{z}$.
$\underline{z}$ must be present.

An example of the form of a
selectq is:
(SELECTQ (CAR X)
        (Q (PRINT FOO) (FIE X))
        ((A E I O U) (VOWEL X))
        (Y (TRY-AGAIN X))
        (COND((NULL X)NIL)
            (T (QUOTE STOP))))
which has 3 cases, Q,(A E I O U)
and Y, and a default condition
which is a cond.

selectq compiles open, and is
therefore very fast; however it
will not work for lists, large
integers or floating point num-
bers since it uses a 24 bit open
compare (an open eq).

prog1[$x_1;x_2;\ldots;x_n$]

This function evaluates its
arguments in order, that is, x_1
then x_2 etc. It returns the
value of its first argument x_1.

prog2[x;y]

Evaluates x, then y and returns
y.

progn[x;y;...;z]

progn evaluates each of its
arguments in sequence, and re-
turns the value of its last
argument as its value. It is an
extension of prog2.

prog[args;e_1;e_2;...e_n]

This feature allows the user to write an ALGOL-like program containing LISP statements to be executed and is identical to the prog in LISP 1.5. The first argument is a list of program variables. The rest is a sequence of (non-atomic) statements (expressions), and atomic symbols used as labels for transfer points. The value of a prog is determined by the function return. If no return is executed, the value of the prog is not guaranteed, but will not give an error.

go[x]

go is the function used to cause a transfer in prog. (GO A) will cause the program to continue at the label A.

A go can be used at any level in a prog. If a go is executed in an interpreted function which is not a prog, it will be executed in the last interpreted prog entered.

return[x]   A return is the normal end of a
                                 prog. Its argument is evaluated
                                 and is the value of the prog in
                                 which it appears. If a return
                                 is executed in an interpreted
                                 function which is not a prog,
                                 the return will be executed in
                                 the last interpreted prog entered.

set[x;y]   This function sets the atom which
                                 is the value of x, to the value
                                 of y, and returns the value of y.

setq[x;y]   This FSUBR is identical to set,
                                 except that the first argument
                                 is not evaluated.
                                 Example: If the value x is c,
                                 and the value of y is b, then
                                 set [x;y] would result in c
                                 having value b, and b returned.
                                 setq[x;y] would result in x
                                 having value b, and b returned.
                                 In both cases, the value of y
                                 is unaffected.

setqq[x;y]   Identical to setq except that
                                 neither argument is evaluated.

Predicates and Logical Connectives

atom[x]   atom[x]=T if x is an atom; NIL
                                 otherwise.

eq[x;y]   The value of eq is T if x and y
                                 are identical atoms, NIL other-
                                 wise. This includes numbers, if
                                 eq is called from an interpreted
                                 function. It is not guaranteed
                                 for floating point numbers and
                                 large integers when used in a
                                 compiled function, since it is
                                 compiled open as a 24 bit compare.

eqp[x;y]   Identical to eq, except that it
                                 is compiled closed, and hence
                                 will work for all numbers in
                                 compiled code.

neq[x:y]   The value of this function is T
                                 if x is not eqp to y, and NIL
                                 otherwise.

nill[]   Defined as NIL

null[x]   eq[x;NIL]

equal[x;y]   The value of this function is T
                                 if x and y are equal, that is,
                                 identical S-expressions, and NIL
                                 otherwise. Identical here means
                                 that they will print identically.

$and[x_1 \ldots x_n]$

This function is an FSUBR and can take an indefinite number of arguments. Its value is the value of its last argument if none of its arguments has value NIL, and is NIL otherwise. Arguments past the first null argument are not evaluated.

$or[x_1; \ldots; x_n]$

or is also an FSUBR and may have an indefinite number of arguments (including 0). or has value NIL if all of its arguments have value NIL, otherwise, it has the value of its first non-null argument. Arguments past this one are not evaluated.

$not[x]$

Same as null

$memb[x;y]$

This function determines if x is a member of list y, i.e. if there is an element of y eq to x. If so it returns the portion of the list starting with that element. If not it returns NIL.

$member[x;y]$

Identical to memb except that it uses equal instead of eq to check membership of x in y.

intersection[x;y]   This function returns with a list
                                 whose elements were members of
                                 both lists x and y.

union[x;y]   This function is entered with two
                                 lists. It returns with a list
                                 consisting of all elements
                                 included on either of the two
                                 original lists. If the same
                                 item is a member of both original
                                 lists, it is included only once
                                 on the new list.

SECTION VI

LIST MANIPULATION AND CONCATENATION

list$[x_1; \ldots; x_n]$

The value of <u>list</u> is a list of the values of its arguments.

append$[x;y]$

This function copies the top level of list <u>x</u> and appends list <u>y</u> to this copy. The value is the combined list.

nconc$[x;y]$

This function is similar to <u>append</u> in effect, but it causes this effect by actually modifying the list structure <u>x</u>, and making the last element in the list <u>x</u> point to the list <u>y</u>. The value of <u>nconc</u> is a pointer to the first list <u>x</u>, but since this first list has now been modified, it is a pointer to the concatenated list.

tconc[x;p]

This function provides an effi-
cient way for placing an item x
at the end of a list. This list
is the first item on p, that is,
car[p]; cdr[p] is a pointer to
the last element in this list; x
is placed on the end of the list
by modifying this structure, and
x is placed on the list as an
item. The effect of this function
is equivalent to
nconc[car[p];list[x]], with cdr[p]
updated to point to the last ele-
ment of the modified list.

lconc[x;p]

This function is similar to tconc,
except that in this case x is a
list. An entire list will be
tacked on the end of car[p], and
cdr[p] will be adjusted to be a
pointer to the last element of
this new combined list. Both
tconc and lconc work correctly
given null arguments.

attach[x;y]

This function attaches the element
x on the front of the list y by
doing an rplaca and an rplacd.
This will not work correctly if
y is an atom. Thus it is similar
to cons, except that it modifies
the contents of the first element
of the non-null list y.

remove[x;1]

The function remove removes all occurrences of x from list 1, giving a copy of x with all elements equal to x removed.

dremove[x;1]

This function is identical to remove, but actually modifies the list 1 when removing x, and returns x itself.

copy[x]

This function makes a copy of the list x. The value of copy is the (location of the) copied list. All levels of x are copied.

reverse[1]

This is a function to reverse the top level of a list. Thus, using reverse on
(A B (C D)) gives ((C D) B A)

dreverse[1]

Identical to reverse but dreverse destroys the list 1 while reversing by modifying pointers, and thus does not use any additional storage.

subst[x;y;z]

This function gives the result of substituting the S-expression x for all occurrences of the atomic symbol y in the S-expression z. It returns a copy of z with the changes made.

dsubst[x;y;z]   Identical to subst, but physically
                               inserts a copy of x for y in z,
                               thus changing the list structure
                               z itself.

sublis[x;y]   Here x is a list of pairs:
                               $((u_1 \cdot v_1)\ (u_2 \cdot v_2)\ \dots\ (u_n \cdot v_n))$

                               The value of sublis[x;y] is the
                               result of substituting each v
                               for the corresponding u in y.
                               Copies the structure y with
                               changes.

subpair[x;y;z]fl   Similar to sublis, except that
                               elements on y are substituted for
                               corresponding atoms on x in z.
                               New structure is created only if
                               needed, or if fl=T.

last[x]   This function has as its value a
                               pointer to the last cell in the
                               list x, and returns NIL if x is
                               an atom. i.e. if x=(A B C) then
                               last [x] = (C)

nth[x;n]

The arguments of <u>nth</u> are a list <u>x</u>
and a positive integer <u>n</u>. Its
value is a list whose first ele-
ment is the nth element of list
<u>x</u>. Thus if n = 1, it returns
the list <u>x</u> itself. If n = 2,
it returns cdr[x]. If n = 3,
it returns cddr[x], etc.
If n = 0 it returns cons[NIL,x].

length[x]

This function has as a value the
length of the list <u>x</u>. If <u>x</u> is
an atom, it returns 0.

SECTION VII

PROPERTY LIST FUNCTIONS

put[x;y;z]

This function puts on the pro-
perty list of x, the label y
foll wed by the property z. The
current value of z replaces any
previous value of z with label y
on this property list.

remprop[x;y]

This function removes all occur-
rences of the property with label
y from the property list of x.

prop[x;y;u]

The function prop searches the
list x for an item that is equal
to y. If such an element is
found, the value of prop is the
rest of the list beginning
immediately after that element.
Otherwise, the value is u[],
where u is a function of no argu-
ments. Its effect is similar to
memb and member, and they are
more efficient when usable.

get[x;y]

This function gets from the list x the item after the atom y on list x. If y is not on the list x, this function returns NIL. For example, get[(A B C D);B] = C.

getp[x;y]

This function gets the property with label y from the property list of x.
NOTE: Both getp and get may be used on property lists. However, since getp searches a list two at a time, the latter allows one to have the same object as both a property and a value. e.g., if the property list of x is
(PROP1 A PROP2 B A C)
        then get[x;A]   = PROP2,
        but getp[x;A]   =   C.

deflist[x;p]

This function is used to put items on property lists. Its first argument x is a list of two element lists. The first of each is a name. The second element is the value to be stored after the property p on the property list of the name. The second argument p is the property that is to be used.

add[x;y;z] This function adds the value z to the list appearing under the property y on the atom x. If x does not have a property y, the effect is the same as put[x;y;list[z]].

assoc[x;a] If a is a list of dotted pairs, then assoc will produce the first pair whose first item is eq to x. If such an item is not found, assoc will return NIL.

sassoc[x;y;u] The function sassoc searches y, which is a list of dotted pairs, for a pair whose first element is equal to x. If such a pair is found, the value of sassoc is this pair. Otherwise, the function u of no arguments is taken as the value of sassoc.

SECTION VIII

FUNCTION DEFINITION AND EVALUATION

getd[x]

This function gets the definition
of the function whose name is
the value of x. If x is not a
defined function, the value of
getd[x] is NIL; if x is a machine
code function, the value is a
number.

putd[x;y]

putd places the value of y into
the function cell of the atom
which is the value of x. This
is the basic way of defining
functions. putd is mnemonic for
put definition on x. The value of
putd is the definition (value of
y).

putdq[x;y]

This function is similar to putd,
but both arguments are considered
quoted, and its value is x.

fntyp[fn]

This function returns NIL if the atom fn is not the name of a defined function. If fn is a function, then fntyp returns one of the following as defined in the section on function types:

EXPR	CEXPR	SUBR
EXPR*	CEXPR*	SUBR*
FEXPR	CFEXPR	FSUBR
FEXPR*	CFEXPR*	FSUBR*

The prefix F indicates unevaluated arguments; the prefix C indicates compiled code; and the suffix * indicates an indefinite number of arguments.

define[x]

The argument of define is a list. Each element of the list is itself a list containing two or more items. In a two-item list, the first item of each element of the list is the name of a function to be defined, and the second item is the defining LAMBDA or NLAMBDA expression. In longer lists, the first item is again the name of the function to be defined. The second is the LAMBDA list of variables and the remainder of the lists are forms for evaluation. As an example, consider the following two equivalent

expressions for defining the
function null.
1) (NULL (LAMBDA (X) (EQ X NIL)))
2) (NULL (X) (EQ X NIL))

define will not allow redefini-
tion of a SUBR or FSUBR.

defineq[x;...;z] This FEXPR is closely related to
define. However, it can take an
indefinite number of arguments,
and it will treat them literally
as if they were quoted. Each of
the arguments must be a list, of
the form described in define.
Using defineq instead of define
allows one to eliminate two pairs
of parentheses in writing func-
tions to be defined for loading
with the function load.

eval[x] eval evaluates the expression x
and returns this value.

evala[x;a] This is the regular eval from
7094 LISP. Its first argument is
a form which is evaluated by us-
ing the values obtained from a,
a list of dotted pairs. That is,
any variables appearing free in
x, that also appear on a, will be
given the value indicated on a.

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evalr[x;a]   Same as evala except with list a
                            reversed. Used by evala.

e[x]   This FEXPR is defined as eval;
                            however, it is shorter and it re-
                            moves the necessity for the extra
                            pair of parentheses for the list
                            of arguments for eval. Thus,
                            when typing into evalquote one
                            can simply type e followed by
                            whatever one would type into eval
                            and have it evaluated.

apply[fn;args]   apply applies the function fn to
                            the arguments args. i.e. the
                            arguments of fn, args, are not
                            evaluated but given to fn direct-
                            ly.

nargs[fn]   Returns NIL if fn is not a func-
                            tion, and the number of arguments
                            of fn if it is. It returns 1 for
                            functions of type
                            EXPR*, FEXPR*, CEXPR*, CFEXPR*,
                            CSUBR* and CFSUBR*.

arglist[fn]   Returns with the list of argu-
                            ments of the function fn. Causes
                            an error if fn is a built-in
                            function or undefined.

arg[n]   This function works with a func-
                                tion of type EXPR* or CEXPR*.
                                It returns argument n of that
                                function. It is undefined if
                                $n \leq 0$ or $n \geq m$ where m is the number
                                of arguments bound.

setarg[n;v]   Sets argument n of an EXPR*
                                function to v.

SECTION IX

THE LISP EDITOR

The LISP editor allows rapid, convenient modification of list
structures. Most often it is used to edit function definitions,
often while the function itself is running. It is another impor-
tant feature which allows good on-line interaction in the BBN-LISP
system.

Editor Language Structure

Let us take a concrete example of a list (not necessarily a func-
tion definition) to be edited. Suppose we are editing the follow-
ing incorrect definition of the append function:

        (LAMBDA (X) Y (COND ((NUL X) Z) (T (CONS (CAR)
            (APPEND (CDR X Y)))))).

At any given moment, the editor's attention is confined to a
single list (generally a subcomponent of the original list being
edited), which it will print when given the command P. To avoid
printing of confusing detail, sublists of sublists will be printed
simply as &. Thus:

    *P
    (LAMBDA (X) Y (COND & &)).

where * indicates that this line was typed by the user.

Only the list on which attention is currently focused may be
changed. Commands thus fall naturally into four classes: moving
around the list structure; making changes in the current list;
printing parts of the list being edited; and entering and leaving
the editor.

Many commands use the convention that an integer designates a
sublist of the current list· For example, if an integer alone
is typed, attention is focused on the designated sublist of the
current list.

Thus:

    *2
    *P
    (X)

The converse command is the number 0, which causes the current
list to revert to its former state. For example, starting again
with the list at the beginning of the section:

    *3 P
    Y
    *0 P
    (LAMBDA (X) Y (COND & &)).

Note the use of several commands on a single line. In BBN LISP,
a carriage return is printed automatically whenever a right paren-
thesis is typed which causes the parenthesis level to become a
zero. Therefore, a non-atomic command is necessarily always the
last command on its line.

In the remaining examples, unless mentioned specifically, it is assumed that the state of the edit is that which existed at the end of the previous example. As above, lines typed by the user are prefixed with an asterisk.

Attention Commands

The two fundamental commands for moving around the structure have already been mentioned: a positive integer n, to examine the nth sublist, and $\emptyset$, to revert to the superlist. If n is a positive integer, then $-n$ examines the nth sublist of the current list starting from the end and counting backwards, i.e. -1 examines the last sublist of the current list.

A more drastic command is ↑, which clears the editor's memory of descent through the structure and reestablishes the top level of the entire list structure being edited as current. Thus:

```
*4 2 1 ↑ P
 (LAMBDA (X) Y (COND & &)).
```

A command similar to n is (NTH n) which caused the list starting with the nth sublist of the current list to become current. Thus:

```
*(NTH 3)
*P
 (Y (COND & &)).
*Ø P
 (LAMBDA (X) Y (COND & &)).
```

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(NTH -n) may also be used, with the expected result:

```
*(NTH -3)
*P +
 ((X) Y (COND & &))
```

The command (F e), where e is any S-expression, searches for an instance of e in the current list, and then acts like NTH, so that for example:

```
*(F Y)
*P
 (Y (COND & &)).
```

A more thorough (and time-consuming) search is provided by (F e T) which searches through the entire structure. Thus:

```
*+(F Z T)
*P
 (Z)
*Ø P
 ((NUL X) Z)
*Ø P
(COND (& Z) (T &))
*Ø P
 (LAMBDA (X) Y (COND & &)).
```

One more variation is provided by (F e n), which finds the nth
occurrence of e anywhere in the structure. The search is done
in printout order, so for example:

```
*↑ (F X 1)
*P
 (X)
*↑ (F X 2)
*P
 (X)
*∅ P
 (NUL X)
*↑ (F X 3)
*∅ P
 (CDR X Y)
```

The argument e of the F commands need not be a literal S-expression.
The symbol & will match any element of a list; the symbol -- as
the last element of a list to be searched for will match the rest
of any list. Thus:

```
*↑(F (NUL &) T)
*P
 (NUL X)
*↑(F (CDR --) T)
*P
 (CDR X Y)
*↑(F (CDR &) T)
 ?
```

The question mark which followed the last command is the editor's
all-purpose error comment: it simply means something was wrong

with the last command. The commands are simple enough that it
is rarely diffic lt to ascertain the nature of the error. A
problem may arise if several commands were stacked on a single
line, since no indication is given of which one caused the error:
in this case the state of the edit can always be discovered by
using P.

Three facilities are available for saving information relating to
the current state of the edit and later retrieving it. At any
stage in the edit, a mark can be made and later returned to. The
commands are MARK, which marks the current state for future
reference: +, which returns to the last mark without destroying
it; and ++, which returns to the last mark and forgets it. For
example:

```
*+ 4 2 P
((NUL X) Z)
*MARK + (F CONS T)
*P
(CONS (CAR) (APPEND &))
*+ P
(LAMBDA (X) Y (COND & &))
*++ P
((NUL X) Z)
*+ P
?
```

This last example demonstrates another facet of the error recovery
mechanism: to avoid further confusion when an error occurs, all
commands on the line beyond the one which caused the error are
forgotten.

A more drastic marking facility is available if it is desired to save the state of the edit in its entirety. Since changes are made as they are typed in, there is no simple way to undo part of an edit. However, the command COPY will make a copy of the entire state of the edit, which may be retrieved with RESTORE. This has the effect of undoing all changes made since COPY was given, since the copy is not affected by editing commands given after the copy was made. This facility is unlike MARK in that a second COPY obliterates the list saved by the first. Furthermore, since RESTORE retrieves the copied edit state and not a copy thereof, subsequent RESTOREs will definitely not have the desired effect.

Frequently it is desired to move or copy a sublist from one place in the structure being edited to another. No command for performing this particular operation is provided. However, it is possible to set a variable to the current list or a sublist thereof. The I command described below can then be used to treat this value exactly as though it had been typed in literally. In particular, the command (S v), where v is a variable name, sets v to the current list. (S v $\emptyset$) may also be used. Thus:

    *↑ (S EL2 2)

will result in setting the value of EL2 to the sublist (X).

Modification commands

Just as most general text editors contain INSERT, REPLACE, and APPEND commands, the LISP editor provides facilities for these three basic operations. To insert the S-expressions $e_1 \ldots e_m$ before sublist n of the current list, one simply gives the command $(-n\ e_1\ \ldots\ e_m)$, thus:

```
*↑ (F CAR T)
*P
 (CAR'
*(-1 CRR)
 P
 (CRR CAR).
```

To replace the $\underline{n}$th sublist with $\underline{e}_1...\underline{e}_m$, one gives the command
(n $e_1...e_m$), for example:

```
*↑(F NUL T)
*P
 (NUL X)
*(1 NULL IS)
*P
 (NULL IS X).
```

And to append at the end of the current list, one writes
(N $e_1...e$), thus:

```
*(N THIS LIST)
*P
 (NULL IS X THIS LIST).
```

Deletions may be accomplished by using the replace operation with
no new S-expressions specified: to restore the list we have just
created to the state in which we presumably want it, we can say:

```
    *(5)
    *(4)
    *(2)
    *P
     (NULL X).
```

Deletions should generally be made from back to front, since other-
wise the indices of later sublists will change as earlier ones
are deleted, e.g. the above sequence of commands given in front
to back order would have been

```
    *(2)
    *(3)
    *(3).
```

Very often one wants to make a simple change in a list structure,
without wanting to know exactly how to trace down the structure
to the point where the emendation is to be made. The command
(R $e_1 e_2$) replaces _all_ occurrences of e_1 in the current list and
all its substructure by e_2. This is done using a variant of
subst called _dsubst_ that runs faster, and physically replaces the
old structure in the list by a copy of the new structure. For
example:

```
    *↑(R Z Y)
    *4 2 P
    ((NUL X) Y)
```

The mechanism by which lists saved with the S command may be used,
among other things, is (I c e_1, ... e_n), which is equivalent to
([atom[c]→c; T→eval[c]] eval[e_1] ... eval[e_n]). Thus for example,

if EL2 has been set to (X) as per the sample above:

```
*↑ (I (CAR (QUOTE (F))) EL2 T)
*P
 (X)
```

because the I command is equivalent to (F (X) T).

Structure changing commands

The commands presented in the last section do not allow convenient
alteration of the list structure itself, as opposed to components
thereof. Ccnsider, for example, the list (A B (C D E) F G). We
can remove the parenthesis around (C D E), which is the third
sublist, by (LO 3) (this stands for take Left paren Out). This
produces the list (A B C D E). LO simply deletes all elements of
the original list beyond the one specified. If we want to preserve
them, we could say (BO 3), take Both parentheses Out, which pro-
duces (A B C D E F G). Conversely, if we want to take the partial
list beginning at B and subordinate it one level, making
(A (B (C D E) F G)), we can say (LI 2), i.e. put a Left parenthe-
sis in before sublist 2 (and a matching right parenthesis at the
end of the list). Again, if we want the matching right parenthe-
sis inserted somewhere other than at the end of the list (after
the F, for example), we can say (BI 2 4), out Both parentheses
In around elements 2 through 4, which results in the list
(A (B (C D E) F) G).

Two other operations of this sort are also possible. If we wanted
to bring only the D and E up to the level of the A B F G, and
leave (C) as a sublist, we can use (RI 3 1), namely move the Right
paren at the end of sublist 3 In to sublist 3 after sublist 1

(of sublist 3). This will produce (A B (C) D E F G). A related operation is (RO 3), which means move the Right parenthesis of sublist 3 Out to the end of the list, producing (A B (C D E F G)). Finally, if it is desired to move a right parenthesis only part-way out, for example to produce (A B (C D E F) G), this can be accomplished by (RO 3) followed by (RI 3 4).

Printing commands

We have already encountered the command P, which prints the current list showing only one level of nesting. To print a selected sub-list in the same way without changing the state of the edit, (P n) is used: for example,

```
* ↑ P
 (LAMBDA (X) Y (COND & &))
*(P 2)
 (X).
```

Furthermore, one may examine the nth sublist (or, if n=0, the current list) to m levels of nesting by using (P n m). The con-vention is that m=3 yields the usual format: several illustrations are given below:

```
*(P Ø 1)
 &
*(P Ø 2)
 (LAMBDA & Y &)
*(P Ø 3)
 (LAMBDA (X) Y (COND & &))
*(P 4 2)
 (COND & &)
*(P 4 4)
 (COND ((NUL X) Z) (T (CONS & &))).
```

Another command which is available for examining the environment
during editing is (E e), which simply prints the value of e with-
out disturbing the state of the edit. This is done under errorset,
so that one can actually try to run the function which one is
editing. It should be mentioned that changes are made as soon as
they are typed in, so that the state of the definition of a func-
tion (which is what is usually being edited) is always exactly
what one expects. Also, the variable l contains the state of the
edit, with the current list being car[l]. Thus, (E (CAR L)) will
cause the current list to be printed by print.

Edit Macros

In editing a set of functions, to make a consistent change in a num-
ber of places, one must give the same sequence of commands a number of
times. For example, to replace all occurrences of calls to
(FOO &) by calls to (FIE & T), (where & stands for any expression),
one would type

    ↑
    (F FOO T)
    (1 FIE)
    (N T)

as many times as the replacement was necessary. To save this
typing, one can define an edit Macro, called RF for example, by
typing

    (M RF ↑ (F FOO T) (1 FIE) (N T))

Then each time you type

     RF

the sequence of commands, following the RF in the definition list,
will be executed. If RF were made the last command in the list,
the sequence would be repeated until FOO could not be found.

The simple ed   cros described above cannot be given any argu-
ments, and will always do exactly the same thing. One can also
define macros which use parameters. For example, to define a
macro to switch two items in a list, one would type

     (M SW (A B) (S SW1 A) (S SW2 B) (I B SW1) (I A SW2))

where the list of argument names (A B) immediately follows the
macro name, SW. To make this macro, SW switch items 2 and 7 in
a list, one would type

     (SW 2 7)

This command would substitute 2 for A, and 7 for B, in the macro
definition following the argument list (A B); and then execute
that sequence of commands with the substituted values. In this
case, the sequence would be

     (S SW1 2)
     (S SW2 7)
     (I 7 S' 1)
     (I 2 SW2)

Note that a macro with no parameters is called by typing an <u>atom</u>

(its name): a macro with parameters must be called by using its name as the first element of a list, followed by the values to be substituted for the parameters of the macro.

All the edit Macro definitions can be found on a free variable called EDITMACROS. This value can be edited by the editor, and will be the cumulative list of all macros defined since the current sysin was done. New definitions of macros supercede old ones. This feature lets you easily expand the repertoire of edit commands, and thus "program" the editor.

Using the editor

As presently interfaced to the outside world, the editor consists of a basic function for editing S-expressions, edite, and three special NLAMBDA functions for editing values, definitions, and property lists, respectively editv, editf, and editp. Thus,

```
*EDITF(APPEND)
 EDIT
```

would be used to begin the edit which has been used as the example. When editing is complete, STOP or OK will cause edite to exit with the edited list as value. The three interface functions all return as value the atom being edited, and place the new value in the appropriate place.

In fact, the work of the editor is done by two functions editcom and editdefault. Editcom assumes the existence of a free variable

L, initialized to <u>list</u> of the list being edited; a free variable
Y, used to hold the copy made by COPY, if any; and a free variable
M, to hold marks made by MARK. It accepts as its argument an
editing command and performs the appropriate transformation on
these three variables. Unrecognizable commands are passed to
<u>editdefault</u>, which is currently defined as λ[[c];error[c]]; the
edit is run by <u>edite</u> under an <u>errorset</u>.

A complete example, starting with the erroneous definition given
at the beginning of Section IX and ending with the correct defini-
tion of <u>append</u>, is given below.

```
    *EDITF(APPEND)
     EDIT
    *(P Ø 1ØØ)
     (LAMBDA (X) Y (COND ((NUL X) Z) (T (CONS (CAR) (APPEND
         (CDR X Y))))))
    *(3)
    *(2 (X Y))
    *P
     (LAMBDA (X Y) (COND & &))
    *(R NUL NULL)
    *(R Z Y)
    *↑(F CAR T)
    *(N X)
    *↑(F CONS T)
    *3 (RI 2 2)
    *P
     (APPEND (CDR X) Y)
    *↑(P Ø 1ØØ)
     (LAMBDA (X Y) (COND ((NULL X) Y) (T (CONS (CAR X) (APPEND
         (CDR X) Y)))))
   *STOP
    APPEND
```

In all fairness, it should be admitted that in this particular
instance it probably would have been faster to type the function
in again. However, LISP functions are typically three times as
big as append and have only one or two errors. It has been found,
after over a year of use at BBN and Berkeley, that the editor just
described does materially decrease the amount of time required
to produce working LISP programs.

A Summary of the Editor Commands

Atoms

n>0	Makes nth element be current level list
n<0	Makes nth element from end be current level list
n=0	Makes previous level be current level list
COPY	Saves a copy of current work
RESTORE	Restores as current work earlier copy
P	Prints current level list to depth 3
↑	Makes current list be the top level list
MARK	Marks this point
←	Makes current level be last marked list
←←	Makes current level be last marked list and forgets mark
STOP or OK	Exit from editor

Other atoms give an error indication of ? if not defined as an
Edit Macro. This can be changed by modifying the routine
editdefault, currently defined as

```
(LAMBDA (C) (ERROR C))
```

Lists

$(n\ e_1\ e_2,\ldots,\ e_k)$ $n>0$ $k\geqslant0$	Replace element $\underline{n}$ by the $\underline{k}$ elements $\underline{e}_1,\ldots,\underline{e}_k$. Deletes the $\underline{n}$th element if $k=0$
$(n\ e_1\ e_2,\ldots,\ e_k)$ $n<0$ $k\geqslant1$	Inserts $\underline{e}_1,\ldots,\underline{e}_k$ before $\underline{n}$th element
$(N\ e_1,\ldots,\ e_k)$	Adds $\underline{e}_1$ to $\underline{e}_k$ at end of current level list
(S name) and (S name $\emptyset$)	Sets name to current level list
(S name n) $n\geqslant1$	Sets name to $\underline{n}$th element
(R old new)	Replaces all occurrences of the old item by new in current level list
(P n m) $n\geqslant0$	Prints element $\underline{n}$ to depth $\underline{m}$ (current list if $n=0$)
(F e)	Finds $\underline{e}$ at current level; "&" matches any item, "--" matches any remaining list
(F e T)	Finds $\underline{e}$ at any level
(F e n) $n\geqslant1$	Finds $\underline{n}$th occurrence of $\underline{e}$ any level

(NTH n) n>1	Makes nth element be first element of current list
n<0	Makes nth element from the end be the first element on the list
(I command $e_1 \ldots e_k$)	Evaluates $e_1 \ldots e_k$ and then performs command as usual. Command can be a number, N, R, F, etc. If command is not atomic, it is evaluated.
(E e)	Evaluates and prints e
(LO n)	Removes left paren before element n (and removes a right paren at end of current list. If there are no more right parens at end of list, elements left hanging "drop off").
(LI n)	Inserts left paren before element n, (and a corresponding right paren at the end of the list).
(RO n)	Removes right paren after element n. It moves it to the end of the current list.
(RI n m)	Inserts right paren in element n after element m. In element n, it moves a right paren from the end of element n which must have more than m elements.

(BO n)   Removes both left and right parens
                                around element n

(BI n m)   Inserts both left and right parens,
                                making a sublist at position n
                                containing elements n to m inclusive.

(M name c_1 c_2...c_n)   Defines name (an atom) as an Edit
                                Macro equivalent to the sequence
                                of commands c_1, c_2,..., c_n.

All other lists cause errors, which print "?". See the statement
on editdefault above.

Edit commands are all interpreted in one function editcom which
accepts a single command as an argument. It and its subfunctions
assume a free variable L initialized to list of the list to be
edited; a free variable Y to hold a copy, if requested, and a
free variable M to hold any marks created. With these restrictions
editcom can be used as a subroutine (as it is in breakin,
described in the section on debugging aids). Edite does the
reading from the teletype, transmits the commands to editcom,
and prints the "?" on errors. All errors and rubouts are caught
by the errorset in edite.

SECTION X

ATOM, ARRAY, AND STORAGE MANIPULATION

pack[x]

The argument x of pack must be a
list of atoms. The value of pack
is a single atom whose print name
is a packed version of the print
names of all the atoms given in the
list. Thus:

pack[(A BC DEF G)] = ABCDEFG
pack[(1 "." 3)] = 1.3 a floating
                     point number

unpack[x]

The argument of unpack should be an
atom. The value of unpack is a list
which contains, in order, the char-
acters which make up the print name
of that atom.

chcon[x;j]

Returns a list of numbers represent-
ing characters in print name of x
which must be an atom.

    j = NIL prin1 representation
      = T   prin2 representation

gensym[]

This function of no argument generates a unique symbol of the form Annnn, in which each of n's is replaced by a digit. Thus, the first one generated is A0001, etc. This is a way of generating new atoms for various uses within the system.

oblist[]

Creates a list of all atoms currently in the system.

reclaim[]

This function initiates a garbage collection and returns with the number of available LISP words in free storage. See minfs. Atoms with no property list, value or function definition, and not used in any list, are collected.

minfs[n]

Sets the minimum amount of free storage which will be maintained by the garbage collector. If, after automatic garbage collection, fewer than n free words are present, (as printed out by the garbage collector) sufficient storage will be added to raise the level to n.

gcgag[x]

If x=T garbage collector will print a message when entered. If x=NIL no message is printed. Previous setting is returned. Initially set to T.

logout[ ]   Deactivates users program and returns
                           the user to the time-sharing system
                           executive.

closer[a;x]   Stores x into location a. Both x
                           and a must be numbers.
                                $a<2^{14}$ actual core location
                                $a \geqslant 2^{14}$ address in virtual
                                       address space.

ilp[x]   Unrestricted car of x.

openr[a]   Value is number in a as defined
                           in closer.

loc[x]   Makes a number out of x, i.e.
                           returns the virtual address of x.

vag[x]   The inverse of loc. Unboxes num-
                           bers. An unboxed number n which
                           doesn't correspond to the address
                           of a list structure or an atom is
                           printed #n e.g. array pointers.

allocate[n]   Allocates an n word block in array
                           (binary program) space. Returns a
                           pointer to the address of the first
                           word allocated. Returns NIL if no
                           more array (binary program) space
                           is available.

statistics[]   Prints out statistics on number
                                of wraparounds of compiled code;
                                number of mapped stores; total
                                number of mapped references (car's,
                                cdr's, cons's, rplaca's, rplacd's,
                                getd's, etc.); total number of
                                drum references.

storage[]   Prints out current status of
                                storage including number of binary
                                program (array) words in use; number
                                of list words (two 940 words) in
                                use; number of 940 words available;
                                and number of words used up for
                                print names.

Array Functions

Arrays and compiled code are both allocated out of a common
array space. Arrays of pointers and unboxed integers may be mani-
pulated by the following three functions:

array[n,p,v]   This function allocates a block of
                                n+4 940 words, of which the first
                                4 are header information. The next
                                $p \leq n$ are cells which will contain
                                unboxed integers, and are initialized
                                to 0. The last $n-p \geq 0$ will contain
                                pointers initialized to v. If p is
                                NIL it is assumed equal to 0 (i.e.,
                                a symbolic array). The value of
                                this function is an unboxed number

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	which is the location of the array in virtual memory, and is called an array pointer.

elt[a;m]

Has as value the mth element of the array pointed to by a. For out of bound calls, if m<1 or m>n, where n is the length of the array a, elt gives element 1 if m<1, or element n if m>n.

seta[a;m;v]

Sets the value of the mth element of a to v. On out-of-bounds reference no store is made. The value of this function is always v. It is the users responsibility to ensure that no pointers are placed in the non-pointer area. Any in that area will not be traced during garbage collection.

arraysize[a]

Returns the size of array a if a is an array pointer.

There will be three parallel functions, arrayf, eltf, and setaf which will manipulate arrays of unboxed floating point numbers. Until they are implemented, only pointers to floating point numbers can be stored in arrays. These will be useless until open floating point arithmetic is available

SECTION XI

FUNCTIONS WITH FUNCTIONAL ARGUMENTS

As in all LISP 1.5 Systems, arguments can be passed which can then
be used as functions. Functions which use functional arguments
should use variables with obscure names to avoid conflict of vari-
able names with variables used free in a functional argument.
There is no "FUNARG device" used in this system. All system func-
tions standardly use variable names consisting of the function
name concatenated with x or fn etc. A FUNARG device may be
implemented in the future.

function[x]   Similar to quote except that x is
                                the name or definition of a function
                                used as an argument; must be used
                                with all functional arguments.

map[x;fn1;fn2]   If fn2 is NIL (i.e. not provided)
                                this function applies the function
                                fn1 to successive tails of the list
                                x. That is, first it computes
                                fn1[x], and then fn1[cdr[x]], etc.
                                until x is NIL; however, if fn2 is
                                provided, fn2[x] is used instead
                                of cdr[x] for the next call for fn1.
                                Thus if fn2 were cddr, alternate
                                elements of the list would be
                                skipped. If fn2 is a conditional

	expression, then the next element to be looked at can be contingent on a computation.
mapc[x;fn1;fn2]	Identical to map, except that fn1[car[x]] is computed each time. If fn2 is NIL, fn1 is applied to each element of the list x in turn.
mapcar[x;fn1;fn2]	If fn2 is NIL, this function applies the function fn1 to each of the elements of the list x. It creates a new list which is a map of the old list in the sense that each element of the new list is the value of applying fn1 to the corresponding element of the old list. If fn2 is provided, fn2[x] is used instead of cdr[x] for each succeeding computation with fn1.
maplist[x;fn1;fn2]	This function computes successively the same values that map computes; it forms a new list consisting of successive values of applications of this function.
mapconc[x;fn1;fn2]	Identical to mapcar except that it does an nconc instead of a cons.
mapcon[x;fn1;fn2]	Identical to maplist except that it does an nconc instead of a cons.

This next set of functions is a slightly different extension of the mapping functions usually found in LISP 1.5. They are all defined by EXPR* type expressions, and make no recursive calls. The first argument to each is a function fn of n arguments. Following this first argument should be n lists. The mapping function iterates down the lists by successive cdrs until any one becomes empty and then returns the value specified. At each iteration, fn is applied to these lists, as specified. For example, the function

pair[x;y] could be defined as
maccar[function[cons];x;y]

mac[fn;x_1;x_2;...;x_n]

Similar to map. Applies fn to successive cdr's of x_1;x_2;...;x_n. Returns NIL.

macc[fn;x_1;x_2;...;x_n]

Similar to mapc. Applies fn to car's of successive cdr's of x_1;x_2;...;x_n. Returns NIL.

maclist[fn;x_1;x_2;...;x_n]

Similar to maplist. Applies fn to successive cdr's of x_1;x_2;...;x_n. Returns a consed list of these values.

maccar[fn;x_1;x_2;...;x_n]

Similar to mapcar. Applies fn to car's of successive cdr's of x_1;x_2;...;x_n. Returns a consed list of these values.

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$maccon[fn:x_1;x_2;\ldots;x_n]$

Similar to mapcon. Applies fn to successive cdr's of $x_1;x_2;\ldots;x_n$. Returns an nconced list of these values.

$macconc[fn;x_1;x_2;\ldots;x_n]$

Similar to mapconc Applies fn to car's of successive cdr's of $x_1;x_2;\ldots;x_n$. Returns an nconced list of these values.

SECTION XII

VARIABLE BINDINGS AND PUSHDOWN LIST FUNCTICNS

A number of schemes have been used in different versions of LISP
for storing the values of variables. These include:

1. Storing values on an association list paired with the
    variable names.

2. Storing values cn the property list of the atom which is
    the name of the variable.

3. Storing values in a special value cell associated with
    the atom name, putting old values on the pushdown list,
    and restoring these values when exiting from a function.

4. Storing values on the pushdown list.

The first three schemes all have the property that values are
scattered throughout list structure space, and, in general, in a
paging environment would require references to many pages to deter-
mine the value of a variable. This would be very undesirable in
our system. In order to avoid this scattering, and possible ex-
cessive drum references, we utilize a variation on the fourth
standard scheme, usually only used for transmitting values of
arguments to compiled functions; that is, we place these values
on the pushdown list. But since we use an interpreter as well as
a compiler, the variable names must be kept. The pushdown list
thus contains pairs, each consisting of a variable name and its

value. The interpreter need only search down the pushdown list
for the binding (value) of a variable.

One advantage of this scheme is that the current top of the
pushdown stack is usually in core, and thus, drum references are
rarely required. Free variables work automatically in a way
similar to the association list scheme.

An additional advantage of this scheme is that it is completely
compatible with compiled functions which pick up their arguments
on the pushdown list from known positions, instead of doing a
search. To keep complete compatibility, our compiled functions
put the names of their arguments on the pushdown list, although
they do not use them to reference variables. Thus, free variables
can be used between compiled and interpreted functions with no
special declarations necessary. The names on the pushdown list
are also very useful in debugging, for they provide a complete
symbolic backtrace in case of error. Thus, this technique, for
a small extra overhead, minimizes drum references, provides
symbolic debugging information, and allows completely free mixing
of compiled and interpreted routines.

There are three pushdown lists used in BBN 940 LISP: the first
is called the parameter pushdown list, and contains pairs of
variable names and values, and temporary storage of pointers;
the second is a number stack for temporary storage of unboxed
numbers; the third is called the control pushdown list, and con-
tains function returns and other control information.

The following functions allow one to interrogate these pushdown
lists from inside another function. The functions, nthfnback,
evalv, setv, variables, and rename take an argument n which, if
positive, is the number of function calls which have been made -

essentially the depth of nesting of functions from the top level.
If n is negative, it references back from the current call level.
The function nthfn returns as a value a positive number which is
the number of call levels from the top (consistent with that
needed by nthfnback, etc.). The argument n to nthfn (n>o) is
interpreted as the nth preceding occurrence (i.e. counting back)
of the function named.

nthfnback[n]	Returns the name of function called at call level (position) n
nthfn[fn;n]	Returns the position (number of call levels from top) of the nth occurrence back of function named fn.
evalv[var;n]	Returns the value of variable var evaluated starting at pushdown list position n
setv[var; n; val]	Sets the value of variable var starting at pushdown position n to value val
variables[n]	Returns list of variable names on pushdown list at pushdown position n
rename[old; n; new]	The variable named old at level n will be renamed new. The push-list cell containing the variable name is changed.

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retfrom[n;v]

Returns from the function at position $\underline{n}$, with value $\underline{v}$. Thus an error[] under a <u>nlsetq</u> is equivalent to a retfrom[nthfn[nlsetq;1];NIL].

backtrace[n;m]

Prints out the untrace normally associated with errors, starting at position $\underline{n}$, and going <u>back</u> to position $\underline{m}$ (i.e. n>m). If n=NIL; it is assumed equal to current position; if m=NIL; it is assumed equal to $\emptyset$.

SECTION XIII

ARITHMETIC FUNCTIONS

Integer Arithmetic

The following functions all work on integers. When given floating
point numbers as arguments, these arguments are fixed (converted
to integers) before <u>any</u> operation is performed. Most of these
functions are compiled as open code.

plus[x_1;x_2;...;x_n]	Returns an integer $x_1+x_2+...+x_n$
minus[x]	- x
diffe.rence[x;y]	This function has for its value the numeric difference between its arguments.
addl[x]	x + 1
subl[x]	x - 1
times[x_1;x_2;...;x_n]	Returns an integer equal to the product of $\underline{x}_1,\underline{x}_2,...\underline{x}_n$
quotient[x;y]	Greatest integer in quotient x/y

remainder [x;y]	This function computes the number theoretic remainder for fixed-point numbers.
divide[x;y]	This function yields a dotted pair whose first member is quotient[x;y] and whose second member is remainder[x;y].
numberp[x]	T if x is a number; NIL otherwise. This function works for floating point numbers as well as integers.
greaterp[x;y]	T if x>y; NIL otherwise
lessp[x;y]	T if x<y; NIL otherwise
zerop[x]	T if x is zero; NIL otherwise
minusp[x]	T if x is negative; NIL otherwise
logand[x;...;z]	This function takes the logical and of all of its argument, and return this value as an integer.
logor[x;...;z]	This function takes the logical or of all of its arguments, and return this value as an integer.
logxor[x_1;...;x_n]	Logical exclusive or of x_1,...,x_n

lsh[n;s]   Performs an arithmetic left
                            shift of s>o on $\underline{n}$. Equivalent
                            to n * ^{s}.

rsh[n;s]   Performs an arithmetic shift of
                            s>o on $\underline{n}$. Equivalent to n * 2^{-s}.

abs[x]   Returns absolute value of $\underline{x}$.

Floating Point Arithmetic

The floating point arithmetic functions available in BBN LISP are
fplus, fminus, ftimes, fquotient, and fgtp. They will accept
mixed arguments, i.e. integer or floating point. Just as the
integer-type functions fix any floating arguments before perfor-
ming their computation, the floating-type functions float
any fixed arguments before performing a computation. Thus the
result of a floating point function is guaranteed to be a floating
point number.

The functions specifically related to floating point are:

fgtp[x;y]	Floating greaterp; compares by subtraction
fix[x]	Returns integer part of $\underline{x}$
float[x]	Produces floating number
floatp[x]	Returns T if $\underline{x}$ is a floating point number, NIL otherwise
fminus[x]	Negative of $\underline{x}$
fltfmt[x]	Output format control; $\underline{x}$ is defined as the time-sharing system formatting of floating point output
fplus[x_1;x_2;...;x_n]	Returns the sum of its arguments

fquotient[x;y]   Returns x/y

ftimes[x_1;x_2;...;x_n]   Product of its arguments

Equal and eqp will compare two floating point numbers for equality,
and will float an integer to compare it to a floating point number.
Eq when compiled is an open 24 bit compare which usually won't
work for arithmetic comparisons. Equal uses eqp.

SECTION XIV

INPUT/CUTPUT FUNCTIONS

Opening and Closing Files

BBN 94ь LISP 1.69 allows the user to have any r·mber of files open
at a given time. Restrictions in the time-sharing system currently
limit this to a maximum of 2, however. A fɪ ↑ is identified by
its LISP File Name.

The three basic file manipulation operations are:

infile[name;type]

used to open for input the file named name, which must be of type
type (i.e., for binary, 2, or for symbolic, 3) if type
is not NIL. Its value is the name of the file if it was opened
successfully, or NIL otherwise. The standird input file is set
to name. T is the name of the teletype as an input (or output)
file.

outfile[name;type]

opens for output the file name, which is set to type type if type
is not NIL, and otherwise to type 3, symbolic. Its value is the
name or NIL as for infile. It sets the standard output file to
name.

closef[x]   Closes the named file. If x is
                             NIL, it attempts to close the
                             standard input file if other than
                             teletype. Failing that, it attempts
                             to close the standard output file
                             if other than teletype. Failing
                             either, it returns NIL. If it
                             closes any file, it returns the
                             name of that file. If it closes
                             either of the standard files, it
                             resets that standard file to tele-
                             type.

openp[x]   Returns NIL if x is not an open
                             file, returns x if x is an open
                             file.

At any given time one input and one output file are selected as
primary (the exact meaning of this is given below). Normally
these are both T for teletype input and output. The primary
input file may be changed by

     input[name]

which sets name to the primary input file. Its value is the name
of the old primary input file. Similarly, the primary output file
may be set with

     output[name]

which has the obvious effect. To read the current setting of the primary input and output files

    input[ ]

and

    output[ ]

may be used.

Input/Output Transmission

Without exception, functions that actually read or write on files may be given an additional argument which is the name of the file on which the operation is to take place. If the additional argument is NIL, the primary file will be used.

The following functions perform output:

    feed[n]

produces n carriage returns and line feeds:

    prin1[a]

prints its argument.

    prin2[a]

prints the expression a with double-quote marks inserted where required for it to read back in properly; both prin1 and prin2 print lists as well as atoms. Neither print a carriage return

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upon termination, both have value <u>a</u>.

> prin3[a]   Prints <u>a</u> using double quotes for
>   separation and break characters
>   specified by <u>setbrk</u> and <u>setsepr</u>
>   as described under <u>ratom</u>
>
> print[x]   Prints the S-expression <u>x</u>;
>   uses <u>prin2</u>; its value is <u>x</u>
>
> spaces [n]   Produces <u>n</u> spaces; its value is
>   NIL
>
> terpri[]   Produces a carriage return and line
>   feed; its value is NIL

If any print function is given an unboxed number <u>n</u>, it will print
it as #<u>n</u> with <u>n</u> in octal.

The print functions <u>print</u>, <u>prin1</u>, <u>prin2</u>, and <u>prin3</u> are all effected
by a level parameter set by

> printlevel[n]

The variable n>Ø controls the number of unpaired left parentheses
which will be printed before any list will be printed as &.

Suppose x = (A (B C (D (E F) G) H) K)

Then if n = 2, print[x] would print

> (A (B C & H) K)

and if n = 3,

    (A (B C (D & G) H) K)

and if n = 0, it prints as just

    &

The value of printlevel[n] is the old parameter setting.

In order to change the level dynamically, while the system is printing at you, you can type control-P followed by a number, i.e. a string of digits, followed by a period. The print level will immediately be set to this number for this printout. If the print routine is currently deeper than the new level all unfinished lists above that level will be terminated by "--)". Thus, if a circular or long list of atoms, is being printed out, typing in

    $P^c\emptyset$.

will cause the list to be terminated. After this printout, the level will be returned to its previous setting. Only <u>printlevel</u> (not P^c) changes the print level permanently.

character[n]	This function outputs on the teletype a single character with octal ascii representation (code) <u>n</u>. <u>n</u> must be a number.

Input Functions

read[]   Reads one S-expression from the
                          current file

rdflx[x]   If x is NIL this function will try
                          to read one S-expression with
                          read[]; if no error occurred in
                          reading, it will return with list
                          of the S-expression that was read.
                          If an error occurs in reading, it
                          returns with NIL. If x is not NIL,
                          it will attempt to read an S-ex-
                          pression and keep attempting to
                          read it until it gets one without
                          an error; each time it tries to
                          read an S-expression and gets an
                          error, it will print out x. In
                          this case it returns with the S-
                          expression itself (not list of the
                          S-expression).

ratom[]   Reads in one atom from the standard
                          file. Separation of atoms is
                          defined by the functions setsepr
                          and setbrk.

ratoms[a]   Calls ratom repeatedly until atom a
                          is read. Returns a list of atoms
                          read not including a.

setsepr[x]   Arguments should be octal numbers,
                              e.g., 155q for carriage return.

setbrk[x]   Characters defined by setbrk will
                              delimit atoms and be returned as
                              separate atoms themselves. Charac-
                              ters defined by setsepr will not be
                              returned and will serve only to
                              separate atoms. For example, to
                              make ratom read in ordinary format,
                              space (0q), comma (14q), and
                              carriage return (155q) are separa-
                              tion characters, and left paren (10q),
                              right paren (11q), and period (16q)
                              are break characters. Thus

                                  setsepr[0q 14q 155q]
                                  setbrk[10q 11q 16q]

                              would set up these characteristics.
                              The value of setsepr and of setbrk
                              is NIL. Use chcon to find numeric
                              codes for characters. The tables
                              are initially set to this standard
                              LISP set of break and separator
                              characters.

setseprc[x]   Same as setsepr except that x is a
                              list of characters.

setbrkc[x]   Same as setbrk except that x is a
                              list of characters.

ratest[x]   Performs two functions depending
             on setting of <u>x</u>.

             If x = T <u>ratest</u> returns indicator
             which is:

                  T if a separator was encountered
                  immediately prior to last atom
                  read by <u>ratom</u>.

                  NIL if there was no separator
                  between last two atoms returned
                  by <u>ratom</u>.

             If x = NIL it returns an indicator
             which is:

                  T if last atom returned by
                  <u>ratom</u> was a break character.

readc[]   Reads the next character. Not
             affected by <u>setsepr</u> and <u>setbrk</u>.

Input/Output Control Function.

These functions perform a variety of operations on the state of
files. Those marked with * do <u>not</u> take the optional extra argu-
ment to indicate a file.

* clearbuf[]   Clears the input buffer of the file
                (not particularly useful for any
                file other than the teletype)

* radix[n;i]   Sets output radix to n and sign
                                indicator to i. If i is T,
                                negative numbers will print as sign
                                and 23 bit value (normal). If i
                                is NIL, all numbers print as 24 bit
                                unsigned integers Returns previous
                                setting.

* control[j]   Sets modes for reading with ratom
                                as follows:

    j = T   Eliminates LISP'S normal line
                                buffering (and also eliminates
                                automatic detection of control-A
                                and control-Q as line-editing
                                characters on the TTY).

    j = NIL   Restores line buffering (normal).

    j = 0   Eliminates the echo of the character
                                being deleted by control -A.

    j = 1   Restores the echo (normal).

* linelength[n]   Sets the length of the print line
                                for all files. The value is the
                                former setting of the line length.

* position[]   Gives the character position on the
                                print line. No guarantees are made
                                about its meaningfulness if output
                                is being done intermittently to more
                                than one file.

* readp[]

Gives T if there is something in the input buffer (either the TSS input buffer or LISP'S line buffer) and NIL otherwise.

Special Functions

sysout[name]

Dumps the entire state of LISP on the file named. This name should not specify a drum file, since mo.e than 38K of information (the maximum for a sequential drum file) will always be written. When the LISP system is reassembled, old sysout files are no longer readable.

sysin[name]

Restores the state of LISP from a sysout file. Sysin may only be done once after entering LISP. If it returns NIL, the file was not found, or was no longer a valid sysout file. Sysin will return T if it was successful.

rbin[x]

Reads one word from x, the specified file. This function returns the word as a number.

wbin[w;x]

Writes one word, w, on file specified by x. W must be a number.

Files opened for binary I-O should be closed by <u>closef</u> in the usual way.

Symbolic File Input

load[x;p]

<u>load</u> is a function which reads successive S-expressions from file <u>x</u> and evaluates each as it is read. If p = T, then <u>load</u> prints the value; otherwise it does not. <u>load</u> continues reading S-expressions and evaluating them, until it reads the single atom STOP followed by a carriage return, at which point it returns the value NIL. Using <u>load</u> is the standard way of getting functions in from files. It never need be to use .. proper d?

Symbolic File ...

 r ? bceprint?   .. ..

prettydef[fns;file;vars]   This function is used for the
                           creation of files containing sys-
                           tems of functions.

The arguments are interpreted as follows:

fns (first argument)   If a list, it is treated as a list
                           of function names. If fns is an
                           atom, it should have as a binding
                           the list of functions for prettydef.
                           The functions on the list are
                           prettyprinted surrounded by a
                           (DEFINEQ ...) so that they can be
                           loaded with load. In addition, a
                           SETQQ will be written which saves
                           the list of functions on the named
                           atom, an. a PRINT will be written
                           which informs the user of the named
                           atom when the file is subsequently
                           loaded.

file (second argument)   The name of the file on which the
                           output is to be written. The
                           following options exist:
                               file=NIL
                                   The standard output file is
                                   used as determined by the
                                   last setting of output.
                               file=atom
                                   The file atom is opened if not
                                   already open, and becomes
                                   the standard output file.

file=list

> Car of the list is assumed
> to be the file name and is
> opened if not already open.
> The standard output file is
> not changed in this case.

vars (third argument)

This option is used where there
are a number of atoms having top
level bindings which the user
wishes to save on the output file.
The following options exist:

If vars is an atom, this atom is
evaluated and should yield a list
of atoms. For each atom in this
list, a SETQQ will be written which
will restore the top level binding
to the atom when the file is loaded.
In addition, a SETQQ and PRINT are
written which save and print vars
as described above for fns. If
the list contains STOP as its last
element, endfile will be called on
the specified file, closing it as
described above.

If vars is a list, the list is
handled as above, except that the
SETQQ and PRINT saving the list
itself are not written.

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As an additional option, if DATE is bound, "THIS FILE WRITTEN ON date" will be printed when the file is loaded.

Examples:

        PRETTYDEF((FOO1 FOO2) /FOO/)

The file /FOO/ is now open, regardless of whether it was open before. Furthermore, /FOO/ is the new output file.

        PRETTYDEF((FOO3 FOO4) (/FIE/))

The file /FIE/ is opened, if necessary, and FOO3 and FOO4 are written on it. /FIE/ is not closed. /FOO/ is still the output file.

        PRETTYDEF((FOO5 FOO6))

        FOO5 and FOO6 are written on /FOO/

        PRETTYDEF((FOO7 FOO8) /FIE/ (STOP))

        FOO7 and FOO8 are written on /FIE/ which is closed with a STOP at the end. The output file is now the teletype.

        SET(FOO(FOO1 FOO2 FOO3))
        PRETTYDEF(FOO /FOO/)

        FOO1, FOO2, FOO3 are written on /FOO/. Also written on the file are (SETQQ FOO (FOO1 FOO2 FOO3))
and
        (PRINT (QUOTE FOO)).

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```
            SET (FOOVAR (ZOT MUMBLE STOP))
            SET (ZOT T)
            SET(MUMBLE NIL))
            PRETTYDEF(FOO /FUM/ FOOVAR)
```

The following are written on /FUM/: definitions of

```
    FOO1, FOO2, and FOO3;
    (SETQQ FOO (FOO1 FOO2 FOO3)):
    (SETQQ FOOVAR (ZOT MUMBLE STOP)); (SETQQ ZOT);
    (SETQQ MUMBLE NIL); (PRINT (QUOTE FOO));
    (PRINT (QUOTE FOOVAR)); and STOP.
    The file is closed.
```

As you might surmise, the most convenient way to use <u>prettydef</u> is
as follows: set a variable to the list of the functions desired
in a particular file, say FOO, and another variable to a list of
variables to be set in that file, if any; <u>prettydef</u> will do the
rest. Then if you do

```
    LOAD(/FUM/)
```

you will see

```
    THIS FILE WAS CREATED ON 4-06 (if you had set DATE)
    FOO
    FOOVAR
    STOP
    and the file will be loaded.
```

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clock[n]   for n=0   value of time of day
                                  clock, i.e., number of
                                  seconds since midnight

                        for n=1   time of day user logged in

                        for n=2   number of seconds of com-
                                  pute time since user
                                  logged in

                        for n=3   time spent in garbage
                                  collections

time[x;n;g]   Time executes the computation x,
                        n number of times, and prints out
                        the number of conses, total time/n
                        if n≠1 and computation time per
                        iteration. Garbage collection
                        time is not included, i.e., it is
                        subtracted out. If n is NIL, it is
                        set to 1. If g is T, garbage col-
                        lection time is also printed.

                        Example:

                        TIME ((CONS NIL NIL) 1000 T)
                        GARBAGE COLLECTION
                        2458 CELLS
                        1 CONSES
                        12/1000=0.12000E-01 SECONDS
                        GARBAGE COLLECTION TIME: 23 SECONDS
                        (NIL)

```
TIME ((PRETTYDEF (QUOTE (FOO))))
0 CONSES
9.0 SECONDS
(FOO)
```

SECTION XV

ERROR HANDLING AND DEBUGGING FUNCTIONS

Error Handling

Errors in BBN LISP are dichotomized into two classes: H errors
for which the user can provide Help on the spot; and $\bar{H}$ errors,
for which no help is possible. $\bar{H}$ errors in the LISP system
normally cause a trap to a routine which prints an error message
and unwinds the pushdown list. While unwinding the pushdown list,
LISP prints the functions which have been entered, and their argu-
ments. The most recently entered function is printed first, etc.
until the top level evalquote if reached. This printout can be
terminated by pressing RUBOUT; this will return you to the LISP
executive. See printlevel for a discussion of modifying the
printout without terminating it. The function

    error[x]   induces an $\bar{H}$ error, printing a
                                      message x

An $\bar{H}$ error can be induced from the console by pressing the RUBOUT.

To prevent $\bar{H}$ errors from stopping all computation by unwinding to
the top level, the following functions can be used:

errorset[form; flag]   This function calls eval with the
value of form. If no error occurs
in evaluation, it returns with a
list containing one element, the
value of eval[form]. If an error
was encountered in the evaluation,
it returns NIL. Note that NIL can
only be returned if there was an
error. A value NIL is returned as
(NIL). The argument flag controls
the printing of error messages. If
flag=T, the error message is printed;
if flag=NIL it is not.

On an error the pushdown list is unwound to the errorset, but no
further. Printing the untrace of functions and arguments on un-
winding to an errorset is controlled by esgag. If an error was
induced by a RUBOUT, a second RUBOUT seen by LISP within 3 seconds
will cause an immediate untrace past all errorsets.

esgag[g]   Sets the unwinding flag for error-
set to g, and returns old value.
If g=T an untrace will be printed
on an unwind to an errorset. If
g=NIL no untrace will be printed.
Initially set to NIL.

ersetq[x]   An FEXPR equivalent to errorset,
with the argument x quoted, and
flag=T.

nlsetq[x]   An FEXPR equivalent to errorset,
                             with x quoted, and flag=NIL.

quit[x]   Induces a "strong" error which
                             will unwind through errorsets to
                             the top level. It prints the
                             error message x. An untrace is
                             printed.

reset[]   Induces a "strong" error which
                             will immediately return you to
                             the top level with no untrace.

There are three types of errors which will allow the user to
fix the mistake, and let the program continue. On these errors,
the system will call breakl, described below, through either of
two functions interrupt or faulteval. These Helpable errors are:

1) An unbound atom
    This usually occurs when an atom has been misspelled or
    not set at the top level, but may also occur because of
    an error in syntax. When this occurs the system will
    print the message

        UNBOUND ATOM name

    where name is the unbound atom, and
    breakl will print

        (name broken)

    Then all the options of breakl are available which will

allow, for example, the user to set the atom, or return a value without setting it, editing the function with the error, etc.

2) Undefined car of form
An H error is induced, and the system types

UNDEFINED CAR OF FORM atom

where atom is the one for which the error occurred. This usually implies that the function has not yet been defined, or that its name was mistyped. The user can then define the function, or return a value etc. The entire form is bound in breakl to a variable called BRK1EXP.

3. Undefined function
If in compiled code, a function is called which is undefined, the system will print

UNDEFINED FUNCTION function

and breakl will then print

(function BROKEN)

where function is the function not defined.

The user may define this function as a LAMBDA expression with spread arguments only, if the function was also undefined at compiled time. The arguments (up to 12 of them) are bound in the interrupt routine to

ARG1, ARG2,..., ARG12

and can be examined in the usual way in breakl.

Inducing H errors

In addition to these errors detected by the system, the user may
induce an H error by typing H^C (H with the control button pressed).
At the next point a function is about to be entered, the system
will type

INTERRUPTED BEFORE function

and breakl will type

(function BROKEN)

At this point the user can examine the status of his computation,
by evaluating variables, or exploring the pushdown list with the
appropriate functions (as of course can be done in any entry to
breakl). The arguments are again bound to

ARG1, ARG2,..., ARG12

As usual, in breakl the function call will be continued if the
user types OK or GO.

In all H errors, the function or atom in question will be bound to
the variable FUNCTION. The form which w'll be evaluated on an
EVAL, GO, or OK is bound to BRK1EXP. The number of interrupts
which have been done before are bound to the variable INTERRUPT.
If a new H error occurs within 6 call levels of an H breakl, the

interrupt routine will not be entered again; an $\overline{H}$ error will be induced, and the user will be back in the earlier H interrupt. If a (GO name) or (RETURN exp) is evaluated, breakl will be left immediately and quietly, and these functions executed in the last interpreted prog on the pushdown list. The user should avoid redefining the functions faulteval and interrupt which are called by the system on H-errors 1 and 2, and H-error 3 and H^c respectively. To suppress all calls to these functions, the user should set the free variable HELPFLAG to NIL.

Debugging Functions

There are three facilities in the system for easily modifying function definitions to allow a user to follow the flow of control and variable bindings in his programs. These three facilities together are called the break package. All three redefine functions in terms of a system function, breakl, described below. Trace modifies a definition of a function fn so that whenever fn is called, its arguments (or some other values specified by the user) are printed. When the value of fn is found it is printed also.

Break modifies the definition of fn so that if a break condition (defined by the user) is satisfied, the process is halted temporarily on a call to fn. The user can then interrogate the state of the machine, perform any computations, and continue or return from the call.

Breakin allows the user to insert a breakpoint inside an expression defining a function. When the breakpoint is hit, and if a break condition (defined by the user) is satisfied, a temporary halt occurs and the user can again investigate the state of the computation.

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Break1

The basic function of the break package is <u>break1</u>. It allows the
user to interrogate the state of the world and to affect the
course of the computation. Once a function is broken, the user
may type in forms to <u>eval</u> and, under heavy errorset protection,
see the value of the computations. In addition, he has the
following options that are specifically recognized by <u>break1</u>:

GO   Releases the break allowing the
computation to proceed. When the
function is evaluated, its value
is printed.

OK   Similar to GO except value is not
printed. When the function is
evaluated, just the function name
is printed.

ERROR   Causes an error return from
<u>break1</u> (all other errors will
maintain the break). This is
a useful way to get back to the
preceding break.

↑   Unwinds to the top - i.e. it
evaluates (RESET).

RETURN <u>form</u>   The value of <u>form</u> is returned as
the value of the function broken.

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EVAL

The computation proceeds but the break is maintained so that after the function is evaluated, a message to this effect is printed and the user can interrogate the value which is stored on the atom VALUE.

Whenever an error occurs inside of a break, either by RUBOUT, or otherwise, the break is maintained. Printing of the function value is done (with a function bpnt∅) to a depth of 4; therefore circularities through the car are permissible.

Break

Break is an NLAMBDA which takes any number of functions to be broken. The functions may be of type EXPR, FEXPR, SUBR, etc., or even undefined. In the case of SUBRs, break will require the names of the arguments and will ask for them on the teletype. Break will usually establish unconditional breaks, i.e. the function will always be broken. To set up a conditional break, one can use a list instead of a function name in the call to break. The first element of the list should be the name of the function, the second the break condition, and the third - if present, a value to be printed. Thus

    BREAK(FOO1 (FOO2 (GREATERP N 5) (CAR X)))
    (FOO1 FOO2)

will cause a break in FOO1 whenever it is called, and a break in FOO2 whenever it is called with N greater than 5. In the latter case, (CAR X) will be printed, using bpnt∅.

In general, if the break condition (the second element of the list)
evaluates to T, the function will be broken, and the value of the
third element will be printed. If the break condition evaluates
to NIL, no break will occur. If the break condition evaluates
to (NIL), then the value of the third element and the value of the
function will be printed, but no break will occur. This is effect-
ively what happens in trace.

Trace

Trace is also an NLAMBDA which takes any number of functions to be
traced. In the normal mode of operation, the arguments of the
function will be bpntⵁed as well as the value. To print out other
values, list the function, followed by the values. Thus

        TRACE(FOO1 (FOO2 Y) (FOO3 (CADR X)Z) (FOO4))
              (FOO1 FOO2 FOO3 FOO4)

will cause FOO1 to be traced, printing out all of its arguments,
FOO2 to be traced printing out Y, FOO3 to be traced printing
(CADR X) and Z, and FOO4 to be traced printing out nothirg except
the name FOO4. In every case, the value of the function is also
printed. The features of trace are exemplified further by the
following:

> (1) The user can specify the values of interest to him in
>   addition to or instead of the arguments of the function,
>   by writing a list headed by the function followed by
>   the values of interest, in place of just the function
>   name.

Example:

```
TRACF(FOO (FOO1 Y (CAR Z)))
(FOO FOO1)


FOO(A B (C D))
FOO:
X=A          ... Arguments of FOO
Y=B
Z=(C D)

FOO1:
Y=A
(CAR Z)=NIL
```

etc.

(2) The user can specify the level to which the arguments, or values, are to be printed by writing (FN N X Y Z ...) in the call to <u>trace</u>. <u>N</u> is taken to be 4 if not specified by this device.

(3) If an error occurs, or RUBOUT is pressed, while a function is being traced, a normal <u>break</u> occurs and, the user can proceed from that point.

Example:

```
TRACE(FACTORIAL)
FACTORIAL

FACTORIAL(2)
FACTORIAL:
N=2

FACTORIAL
N=1

FACTORIAL:
RUBOUT        ... RUBOUT pressed here

(FACTORIAL BROKEN)  ... break occurs
N
O
EVAL

FACTORIAL EVALUATED
FACTORIAL
1
OK
FACTORIAL  ... exit from break

FACTORIAL = 1

FACTORIAL = 2
2
```

Breakin

The third way to use breakl is by means of breakin. Breakin
inserts a call to breakl inside of a function definition. In
other words, although it is impossible to break on eq, or quote,
because so many functions use it, it is possible to break at the
point eq or quote is called from some other function.

Breakin is a function of four arguments: FN, WHERE, WHEN, and WHAT.
FN, WHEN, and WHAT play the same role as the three arguments shown
when break is called with a list instead of an atom, i.e. they
specify under what conditions a break should occur, and what is
to be printed. The second argument, WHERE, specifies where the
break is to be inserted.

WHERE can be either (BEFORE ...) (AFTER ...) (AROUND ...). "..."
is used by the editor's find command to locate the correct point.
Thus (BEFORE COND 3) will break before the third COND, and
(AROUND (SETQ X --)) will break around the first place that X is
set. With the exception of labels in a top level PROG, you cannot
specify a BREAK AROUND, BEFORE, or AFTER an atom, because breakin
automatically changes the atom to (atom --) when calling the
editor. Thus, (BEFORE COND 3) is the same as (BEFORE (COND --) 3).

The first time that breakin is called, it copies the function
definition. Subsequent times it merely searches for the appro-
priate location and smashes the function definition. If the loca-
tion is not found, breakin prints "?". If the function is a
machine code function or undefined, it is not possible to breakin-
side of it.

Unbreak

Unbreak restores functions modified by break, trace, or breakin
to their original state. It is possible to do multiple breaks,
traces or breakins in any combination without first performing
unbreak. Unbreak is an NLAMBDA which takes an indefinite
number of functions to be restored. The variable ALL is set to a
list of all functions broken. Unbreak[ALL] will restore all func-
tions to their original state. Since unbreak[FOO] does not remove
FOO from the list ALL, a subsequent unbreak[ALL] will cause
(FOO NOT BROKEN) to appear in the value of unbreak.

THE COMPILER AND LAP

The Compiler

The compiler is a separate sysout file on the system tape, usually
called COMPILER. To use the compiler, copy your symbolic files
onto the drum, enter LISP and do a SYSIN (COMPILER). You can now
load your functions, thus defining them, and then use the function
compile; or you can compile directly from drum using rcompile. The
latter is recommended to avoid a clash of function names with the
compiler. The compiler compiles to a LAP2 code which can be
written out symbolically on the drum and loaded into any standard
system, using loadc.

     compile[x]   This will compile all the functions
                                   on the list x

                                   example: COMPILE((FOO FIE))
                                   will compile FOO and FIE if they
                                   are defined

     rcompile[]   This will compile from a drum
                                   file whose name will be requested
                                   after the compset questions have
                                   been answered

When either of these functions has been called, they call a function compset which asks a number of questions. Those that can be answered "yes" or "no" can be answered with YES, Y, or T for YES; and NO, N, or NIL for NO. The questions are:

(SETUP - TYPEOUT?)

This question should be answered YES only if you want to see the LAP and LAP2 code produced by the compiler printed on the teletype. If you answer 1 or 2 you will see the output of pass 1 or 2, respectively of the compiler. Usually one should answer NO to this question.

(STORE AND REDEFINE?)

This question should be usually answered NO, unless you want to work with your functions within the compiler system. If you answer YES, you will be asked the question

(SAVE EXPRS?)

If you answer this YES, the exprs will be saved on the property list of the function name. Otherwise they will be discarded.

(NO-SPREAD NLAMBDAS-)

If there are any NLAMBDA's with atomic argument lists called from your functions to be compiled which are not defined, answer the question with one of the following:

S   Means Same list as now on the
                                        free variable NLAMA

ADD $(fn_1;...;fn_k)$	Add fn_1 to fn_k to list saved on NLAMA.
REMOVE $(fn_1;...;fn_k)$	Remove functions from NLAMA
EDIT	The editor will be called and you can edit the list of functions.
$(fn_1;...;fn_k)$	Set NLAMA to the list of functions
NIL, N, NO	Set NLAMA to NIL

Any other atom will cause a question mark to be printed and let you answer again. Then compset will ask:

(SPREAD NLAMBDAS-)

Answer in the same way. The free variable used by the compiler is called NLAMS this time.

(OUTPUT FILE)

This question is always asked. You should usually provide the name of a drum file on which you wish to save the LAP2 code generated. If you answer T, TTY or TELETYPE, the listing will be typed out on the teletype. If you answer N, NOTHING or NIL, output will not be done. If the file named is already open, it will continue to be used.

When the compiler is operating, it will normally print out the name of the function compiling, a list of its bound variables and a list of its free variables. When compile returns, it prints

its list of the functions compiled. The value of r̲c̲o̲m̲p̲i̲l̲e̲ is NIL.

When you have finished compiling all the functions you wish to
dump on one drum file, print NIL on that file and close the file
with closef[name].

The code dumped on the file can be loaded into any standard system
by using

        loadc[file;fl ·]

where if flag=T the names of the functions loaded will be printed.

Affecting the Compiled Code

There are three ways you can affect code compiled for you. You
can make a function f̲n̲ compile open (as an open LAMBDA expression)
by putting the expression defining it (including the LAMBDA) on
the property list of f̲n̲ after the flag MACRO, and adding f̲n̲ to the
list which is the value of OPENFNS. A̲b̲s̲ and m̲e̲m̲b̲ are functions
currently compiled open. The effect is the same as if you had

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written the LAMBDA expression in place of _fn_ wherever it appears
in a function being compiled. This saves the time necessary to
call a function (about a millisecond) at the price of more
compiled code generated.

By putting on the property list of _fn_ under the flag MACRO an
expression starting with an atom other than LAMBDA, one can obtain
the usual MACRO feature of LISP. The atom which starts the list
is bound to _cdr_ of the form in which _fn_ appears. The expression
following the atom is evaluated, and the results of this evaluation
are compiled. _List_, _mapc_ and _map_ are compiled using this technique.
For example: _list_ has on its property list the expression
(X (GLIST X)), where _glist_ is defined as

> (LAMBDA(L) (COND((NULL L)NIL) (T (LIST (QUOTE CONS) (CAR L)
> (GLIST (CDR L)))))))

If the value of the result of this evaluation is the atom,
INSTRUCTIONS, no code will be generated. It is then assumed the
evaluation was done for effect and the necessary code has been
added. This is a way of giving direct instructions to the _compiler_
if you understand it.

Finally, an expression following MACRO on the property list can
start with a list of atoms which are dummy variables for a substi-
tution MACRO. Each atom is paired with a corresponding element
in the form containing _fn_. Then these elements are substituted
for their paired atoms in the expression following the list of
atoms, and this substituted expression is compiled. The functions

> _addl_, _subl_, _neq_, _zerop_, _lessp_, _minusp_, _difference_, _ersetq_
> and _nlsetq_

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are all compiled open using these substitution macros. For example,
on the property list of <u>addl</u> is the expression ((X)(PLUS X 1)).

LAP and LAP2

The compiler has two main passes. The first compiles into a
fairly powerful macro language we call LAP; and this is expanded
into a simple assembly language called LAP2. The user can write
code directly in LAP to be compiled for LISP. It can be processed
by the function

  lap[fn;v;free;m;c]

Where <u>fn</u> is a function name; <u>v</u> is its list of bound variables;
<u>free</u> is a list of variables used free; <u>m</u> is the maximum position
used on the pushdown list; and <u>c</u> is the code to be compiled. LAP
expects the flag LAPFLG to be set to NIL, T, 1, or 2 to determine
printout on none, all, first or second pass code respectively.
The variable STRF should be T or NIL, to store or not store the
definition. The variable SVFLG should have value NIL (T only to
save expr's) and LCFIL should be set to the name of an open file
on which the output is to be placed. FTYP should have value EXPR.

The code is a list of instructions, which are lists, and atoms
which are treated as labels. Instructions are lists with at least
two elements. The first element, <u>fn</u>, can be an op code, a substi-
tution macro, a lambda macro, or a function macro. These LAP
macros are completely separate from the compiler macros. In the
first three cases, <u>fn</u> has on its property list a property OPD with
a value we will call <u>mc</u>. A function macro is the default case,
and a list of code to be used is computed by applying <u>fn</u> to <u>cdr</u>
of the instruction, and this new list is assembled. Useful function

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macros in the system will be described later.

If mc is a number, then fn is an opcode of the 940. The codes
defined at the moment, with their values, are listed at the end
of this section.

Instructions containing these codes as first elements are dumped
in symbolic form and at load time are added to the second of the
instruction. If the third element is I, the index bit is set in
the instruction.

The substitution macros are those where mc is a list which starts
with a list of dummy variables for the macro. Corresponding ele-
ments of the instruction are substituted for the variables in the
macro which is cdr[mc], and this new list of instructions is com-
piled, before the next instruction on the original code is compiled.
When mc starts with LAMBDA, (a lambda macro) similarly to the
default case, a list of instructions is computed by applying mc
to cdr of the instruction. The substitution and lambda macros
in the system are listed at the end of this section.

The important ones of this group are: (where A indicates accumulator)

(LDV X)	Load variable $\underline{X}$ into A
(STV X)	Stores A to $\underline{X}$
(LDT N)	Load A from stack position $\underline{N}$ (a stack position is a pair of 940 words n>0)
(STT N)	Store A in stack position $\underline{N}$ and store 0 in variable slot. This is important to prevent garbage collector foul ups.
(NSTT N)	Store A in stack position $\underline{N}$, do not store 0.
(LQT X)	Load $\underline{X}$ quoted as a constant
(LDN N)	Load an unboxed integer from position $\underline{N}$
(STN N)	Store an unboxed integer in position $\underline{N}$
(CLL L K U)	Call function $\underline{L}$ with K/2 args, and U/2 positions used up on the pushlist through last argument of function called
(CLLA L K U)	Calls a functional argument $\underline{L}$ as above
(RET)	Standard return, only one per function is usual
(BE N B)	Branch to $\underline{B}$ if A=N
(BNE N B)	Branch to $\underline{B}$ if A≠N
(BN B)	Branch to $\underline{B}$ if A=NIL
(BNN B)	Branch to $\underline{B}$ if A≠NIL
(BA B)	Branch to $\underline{B}$ if A an atom
(BNA B)	Branch to $\underline{B}$ if A not atom
(BI B)	Branch to $\underline{B}$ if A a number
(BNI B)	Branch to B if A not number
(BIS B L)	Branch to $\underline{B}$ if A=L a quoted constant
(BNS B L)	Branch to B if A≠L a quoted constant
(JUMP B)	Branch to B

(CONSCLL N)	Calling sequence for <u>cons</u> of element in stack position <u>N</u> with contents of A.
(CCALL OF	Used with either op=CARCLL or op=CDRCLL to call <u>car</u> or <u>cdr</u> A.

The important function macros are:

(PRGREF OP B)	This must be used for all instructions whose address <u>B</u> is a number relative to the beginning of the code and therefore must be relocated on loading. In computing <u>B</u>, remember that LAP inserts 4 instructions at the beginning of your code for initialization.
(BRANCH OP B)	Must be used for all instructions which reference a label (branch point) in the code.
(RELREF OP N)	Used when <u>N</u> is relative to current location.
(LITREF OP EXP)	Stores <u>EXP</u> in a list of literals and computes the address of the literal for use in the compiled code. Used to get any literal quantity into the code.
(VREF OP X)	Computes the position on the stack of the variable named <u>X</u>.
(STKREF OP N)	Computes the actual address on stack of position <u>N</u>.

For further information, consult the document "An Annotated LISP Compiler" by Bobrow, Murphy and Deutsch (forthcoming).

MACROS for the compiler

The following expression when loaded with the compiler defines
all the MACROS used by the compiler.

```
(DEFLIST(QUOTE(
  (LIST (X (GLIST X)))
  (ADD1 ((X)
      (PLUS X 1)))
  (SUB1 ((X)
      (PLUS X -1)))
  (NEQ ((Y Y)
      (NOT (EQ X Y))))
  (ZEROP ((X)
      (EQ X 0)))
  (LESSP ((X Y)
      (GREATERP Y X)))
  (MINUSP ((X)
      (GREATERP 0 X)))
  (DIFFERENCE ((X Y)
      (PLUS X (MINUS Y))))
  (ABS (LAMBDA (X)
      (COND
        ((GREATERP 0 X)
          (MINUS X))
        (T X))))
  (ERSETQ ((X)
      (ERRORSET (QUOTE X)
        T)))
  (MAP (X (LIST (SUBPAIR (QUOTE (MAPF MAPF2))
          (LIST (CFNP (CADR X))
            (COND
              ((CDDR X)
                (CFNP (CADDR X)))
              (T (QUOTE CDR))))
          (QUOTE (LAMBDA (MAPX)
            (PROG NIL
              LP  (COND
                    ((NULL MAPX)
                      (RETURN)))
                  (MAPF MAPX)
                  (SETQ MAPX (MAPF2 MAPX))
                  (GO LP)
            ))))
        (CAR X)))))
```

```
(MAPC (X (LIST (SUBPAIR (QUOTE (MAPCF MAPCF2))
           (LIST (CFNP (CADR X))
              (COND
                 ((CDDR X)
                    (CFNP (CADDR X)))
                 (T (QUOTE CDR))))
           (QUOTE (LAMBDA (MAPCX)
              (PROG NIL
                 LP  (COND
                        ((NULL MAPCX)
                           (RETURN)))
                        (MAPCF (CAR MAPCX))
                        (SETQ MAPCX (MAPCF2 MAPCX))
                        (GO LP)
              ))))
          (CAR X))))
(MEMB (LAMBDA (X Y)
     (PROG NIL
        LP  (RETURN (COND
               ((ATOM Y)
                  NIL)
               ((EQ X (CAR Y))
                  Y)
               (T (SETQ Y (CDR Y))
                  (GO LP))))
     )))
(NLSETQ ((X)
     (ERRORSET (QUOTE X)
        NIL)))
(VAG (X (CEXPR (CAR X))
     (COND
        ((EQ (CAADR CODE)
            (QUOTE ENBOX))
          (RPLACA (CDR CODE)))
        (T (STORE (QUOTE (UNBOX)))))
     (QUOTE INSTRUCTIONS)))
 (LOC (X (CEXPR (CAR X))
     (COND
        ((EQ (CAADR CODE)
            (QUOTE UNBOX))
          (RPLACA (CDR CODE)))
        (T (BOX SP)))
     (QUOTE INSTRUCTIONS)))
 (ARG (X (CEXPR (LIST (QUOTE VAG)
           (CAR X)))
     (STORE (LIST (QUOTE VREF)
           (QUOTE SUB)
           (COND
              (ARGARG)
              (T (ERROR (QUOTE (FUNCTION 'ARG' NOT LEGAL))))))
)
     (STORE (LIST (QUOTE ARGN)
           ARGARG))
     (QUOTE INSTRUCTIONS)))
))(QUOTE MACRO))
```

LAP MACROS

The following expression when loaded with the compiler defines
the substitution and lambda macros for Lap.

```
(DEFLIST(QUOTE(
  (CSP1 ((LV LF LT)
      (LITREF LDA LV)
      (LITREF LDX LF)
      (LITREF LDB LT)
      (PRGREF VAL (PLUS ENTER PLITORG 1))))
  (VST1 ((PP LV V)
      (LITREF LDA PP)
      (LITREF LDB LV)
      (PRGREF VAL (PLUS IPV PLITORG V))))
  (BE ((N B)
      (STKREF SKE N)
      (RELREF BRU 2)
      (JUMP B)))
  (BNE ((N B)
      (STKREF SKE N)
      (JUMP B)))
  (LDV (LAMBDA (S)
      (VREF (QUOTE LDA)
        S)))
  (STV (LAMBDA (S)
      (VREF (QUOTE STA)
        S)))
  (LDT (LAMBDA (S)
      (STKREF (QUOTE LDA)
        S)))
  (STT (LAMBDA (S)
      (STKREF (QUOTE STA)
        S)))
  (NSTT (LAMBDA (S)
      (STKREF (QUOTE NSTA)
        S)))
  (LQT (LAMBDA (X)
      (LITREF (QUOTE LDA)
        X)))
  (LDN (LAMBDA (S)
      (NREF (QUOTE LDA)
        S)))
```

```
(STN (LAMBDA (N)
    (NREF (QUOTE STA)
       N)))
(CLL ((L K U)
    (LITREF LDA U)
    (LITREF LDB K)
    (LITREF CLLX L)))
(CLLA ((L K U)
    (LITREF LDA U)
    (LITREF LDB K)
    (VREF CLLXA L)))
(ARGN ((A)
    (LSH 1)
    (ARGSUB A)
    (ADD PPPTR)
    (CAXB 0)
    (LDA 0 1)
    (CBX 0)))
(ARGSUB (LAMBDA NIL
    (LITREF (QUOTE ADD)
      (PLUS -2 (VREF1 A)))))
(RET (NIL (VAL RETURN)))
(BN ((B)
    (SKE SYSNIL)
    (RELREF BRU 2)
    (JUMP B)))
(BNN ((B)
    (SKE SYSNIL)
    (JUMP B)))
(BA ((B)
    (SKG SYSTAT)
    (RELREF BRU 2)
    (JUMP B)))
(BNA ((B)
    (SKG SYSTAT)
    (JUMP B)))
```

```
         (UNBOX (NIL (VAL UNBOX)))
         (ENBOX ((N)
              (VAL (PLUS ENBOX N))))
        (NEG (NIL (CNA 0)))
        (DVD ((N X)
              (RSH 23)
              (DIV N X)))
         (DIVIDE ((S)
              (STTN S)
              (SWAP 0)
              (ENBOX S)
              (STKREF SXMA S)
              (ENBOX S)
              (STKREF XMA S)
              (CONSCLL S)))
       (BI ((B)
              (SKG SYSNUM)
              (RELREF BRU 2)
              (JUMP B)))
       (BNI ((B)
              (SKG SYSNUM)
              (JUMP B)))
       (BIS ((B L)..
              (LITREF1 SKE L)
              (RELREF BRU 2)
              (JUMP B)))
       (BNS ((B L)
              (LITREF1 SKE L)
              (JUMP B)))
      (CONSCLL ((N)
              (CAB 0)
              (STKREF LDA N)
              (VAL (PLUS CONSCLL (TIMES N 2)))))
      (CCALL ((OP)
              (VAL OP)
              (LDX PPPTR)))
      (CLLX ((N)
              (VAL (PLUS XCLL N))))
      (CLLXA ((N X)
              (VAL (PLUS XCLL N X))))
      (SWAP (NIL (XAB 0)))
      (JUMP ((B)
              (PRGREF BRU (GBS B))))
     (MPY ((N X)
              (MUL N X)
              (LSH 23)))
  ))(QUOTE OPD))
```

OPCODES currently defined for LAP

The following expression loaded with the compiler defines the
Opcodes for Lap.

```
(DEFLIST(QUOTE(         (CAXB 46004400)
   (LDA 76000000)       (CBX 46000200)
   (STA 35000000)       (CNA 46010000)
   (NSTA 35000000)      (BRU 1000000)
   (LDB 75000000)       (BRX 41000000)
   (STB 36000000)       (BRM 43000000)
   (LDX 71000000)       (BRR 51000000)
   (STX 37000000)       (SKE 50000000)
   (EAX 77000000)       (SKG 73000000)
   (XMA 62000000)       (SKM 70000000)
   (SXMA 62000000)      (SKA 72000000)
   (ADD 55000000)       (SKB 52000000)
   (ADM 63000000)       (SKN 53000000)
   (MIN 61000000)       (SKR 60000000)
   (SUB 54000000)       (RSH 66000000)
   (MUL 64000000)       (LRSH 66240000)
   (DIV 65000000)       (RCY 66200000)
   (ETR 14000000)       (LSH 67000000)
   (MRG 16000000)       (LCY 67200000)
   (EOR 17000000)       (NOP 20000000)
   (CLA 46000010)       (EXU 23000000)
   (CLB 46000020)       (VAL 00)
   (CAB 46000040)       (BIO 576000000)
   (CBA 46000100)       (BRS 573000000)
   (XAB 46000140)       (CTRL 572000000)
                     ))(QUOTE OPD))
```

INDEX TO FUNCTIONS

Following is a list of all atoms with initialized top
level values in the basic system and those values.

blank	space
space	space
tab	tab
comma	,
eqsign	=
xeqs	=
f	nil'
nil	nil
period	.
pluss	+
lpar	(
rpar	)
slash	/
t	t
t	t
qmark	?
xdol	$
xsqu	'
xdqu	"
xlbr	[
xrbr	]
xarr	←
uparr	↑
colon	:
xgreater	>
xlesser	<
xnum	#
xper	%
xamp	&
xat	@

xsem	;
xe:claim	!
xcr	carriage return
bkslash	\

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13. ABSTRACT

This report describes the LISP system implemented at BBN on the SDS 940 Computer. This LISP is an upward compatible extension of LISP 1.5 for the IBM 7090, with a number of new features which make it work well as an on-line language. These new features include tracing, and conditional breakpoints in functions for debugging and a sophisticated LISP oriented editor. The BBN 940 LISP SYSTEM has a large memory store (approximately 50,000 free words) utilizing special paging techniques for a drum to provide reasonable computation times. The system includes both an interpreter, a fully compatible compiler, and an assembly language facility for inserting machine code subroutines.

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	Paging Systems						
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	List Structures						
	Symbol Manipulation Language						

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